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FAO Fisheries Reports No. 6, Vol. 3
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PROCEEDINGS OF THE WORLD SCIENTIFIC MEETING ON THE BIOLOGY OF TUNAS AND RELATED SPECIES

ACTES DE LA RÉUNION SCIENTIFIQUE MONDIALE SUR LA BIOLOGIE DU THON ET DES ESPÈCES VOISINES

ACTAS DE LA REUNION CIENTIFICA MUNDIAL SOBRE BIOLOGIA DEL ATUN Y ESPECIES AFINES

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ORGANISATION DES NATIONS UNIES POUR L'ALIMENTATION ET L'AGRICULTURE
ORGANIZACION DE LAS NACIONES UNIDAS PARA LA AGRICULTURA Y LA ALIMENTACION
Rome, 1963

FAO FISHERIES REPORTS

This is the sixth in a series of reports of meetings, surveys and other activities of FAO Fisheries Division.

Other documents in this series are:

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Ce rapport est le sixième d'une série comprenant des rapports de réunions, des études générales et des rapports sur d'autres activités de la Division des pêches de la FAO.

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Fle/R5	Economic effects of fishery regulation	1962
Flb/R6.1 (En)	Proceedings of the world scientific meeting on the biology of tunas and related species, Vol 1 — report	1963
(Fr)	Actes de la réunion scientifique mondiale sur la biologie du thon et des espèces voisines, Vol. 1 — rapport	1963
(Es)	Actas de la reunión científica mundial sobre biología del atún y especies afines, Vol. 1 — informe	1963
Flb/R6.2	Proceedings of the world scientific meeting on the biology of tunas and related species, Vol. 2 — synopses	1963
	Actes de la réunion scientifique mondiale sur la biologie du thon et des espèces voisines, Vol. 2 — exposés synoptiques	1963
	Actas de la reunión científica mundial sobre biología del atún y especies afines, Vol. 2 — sinopsis	1963
Flb/R6.3	Proceedings of the world scientific meeting on the biology of tunas and related species, Vol. 3 — methodological papers and experience papers	1963
	Actes de la réunion scientifique mondiale sur la biologie du thon et des espèces voisines, Vol. 3 — compte-rendus de méthodes et d'expérience	1963
	Actas de la reunión científica mundial sobre biología del atún y especies afines, Vol. 3 — trabajos metodológicos y trabajos de investigación.	1963
Fle/R7 (En)	Report of the third session — continuing working party on fishery statistics in the North Atlantic area	1963

Unserialized reports dated earlier than January 1962 are listed in the FAO Catalogue of Fisheries Publications and Documents (1962). Certain unserialized reports may be reprinted in this series as the unserialized versions go out of print.

Les rapports sans indication de série, portant une date antérieure à janvier 1962, figurent dans le Catalogue FAO des publications et documents sur les pêches. Si ces rapports sont reproduits après épuisement de l'édition actuelle, ils seront incorporés à la présente série.

Los informes fuera de serie, de fecha anterior a enero de 1962, están incluídos en el Catálogo FAO de Publicaciones y Documentos de Pesca. Algunos informes fuera de serie pueden ser reimpresos dentro de esta serie cuando su edición anterior queda agotada.

FAO Fisheries Reports No. 6. Vol. 3 FIb/R6. 3

PROCEEDINGS OF THE WORLD SCIENTIFIC MEETING ON THE BIOLOGY OF TUNAS AND RELATED SPECIES

ACTES DE LA REUNION SCIENTIFIQUE MONDIALE SUR LA BIOLOGIE DU THON ET DES ESPECES VOISINES

ACTAS DE LA REUNION CIENTIFICA MUNDIAL SOBRE BIOLOGIA DEL ATUN Y ESPECIES AFINES

La Jolla, California, U.S.A., 2 - 14 July 1962

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Volume 3 - Methodological and Experience Papers

Compte-rendus de Methodes et d'Expériences

Trabajos Metodológicos y de Investigación

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ORGANISATION DES NATIONS UNIES POUR L'ALIMENTATION ET L'AGRICULTURE
ORGANIZACION DE LAS NACIONES UNIDAS PARA LA AGRICULTURA Y LA ALIMENTACION
Rome, 1963

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PREPARATION OF THIS VOLUME

This volume contains the corrected Methodological and Experience Papers, which were distributed to the participants and to the contributors of the World Scientific Meeting on the Biology of Tunas and Related Species, in La Jolla, California, 2-14 July 1962, and to other interested persons, except for Experience Papers Nos. 41 - 46, which were prepared after the Meeting. Experience Paper No. 47 was originally distributed to the participants and to the contributors as Information Paper No. 2.

The first volume of the Proceedings contained the Report of the meeting, and the second contained the Species Synopsis (see inside front cover). The fourth volume will be a bibliography on tunas, which will include, among others, all the references to papers given in volumes 2 and 3.

The views expressed in the papers are those of the con-

PREPARATION DE CE VOLUME

Ce volume contient les compte-rendus de Méthodes et d'Expériences corrigés, qui ont été distribués aux participants et aux collaborateurs à la Réunion Scientifique Mondiale sur la Biologie du Thon et des Espèces Voisines , La Jolla, California, du 2-14 juillet 1962, ainsi qu'à d'autres personnes y ayant porté intérêt, à l'exception des compte-rendus d'Expérience n° 41 - 46, qui ont été préparés après la Réunion. Le compte-rendu d'Expérience n°47 a d'abord été distribué aux participants et aux collaborateurs en tant que le compte-rendu d'Expérience n°2.

Le premier volume des Débats renfermait le Rapport de la Réunion et le deuxième les exposés synoptiques (voir l'intérieur de la couverture). Le quatrième volume sera une bibliographie consacrée aux thons qui comportera entre autres toutes les références aux

PREPARACION DE ESTE VOLUMEN

Este volumen contiene, corregidos, los documentos Trabajos Metodológicos y de Investigación que se distribuyeron a los participantes y colaboradores a la Reunión Científica Mundial sobre Biología del Atún y Especies afines, celebrada en La Jolla, California, del 2 al 14 de julio de 1962, así como a otras personas interesadas en el tema, con la excepción de los Documentos de Investigación Nos. 41 a 46 que se prepararon después de la Reunión. El Documento de Investigación No. 47 se distribuyó originalmente a los participantes y colaboradores como Documento Informativo No. 2.

El primer volumen de las Actas contiene el Informe sobre la Reunión, y el segundo las Sinopsis de Especies (véase al dorso de la cubierta). El cuarto volumen será una bibliografía sobre los atunes, que incluirá, entre otras referencias, todas las mencionadas en los volúmenes 2 y 3.

tributors, and not necessarily those of the Food and Agriculture Organization of the United Nations.

The following persons helped in preparing this volume :

articles se trouvant dans les volumes 2 et 3.

Les opinions exprimées dans les articles sont celles des auteurs et pas nécéssairement celles de l'Organisation des Nations Unies pour l'Alimentation et l'Agriculture.

Les personnes suivantes ont aidé à la préparation de ce volume:

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Las personas siguientes contribuyeron a la preparación de este volumen:

Distribution

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CONTENTS

Page no.

METHODOLOGICAL PAPERS

1A A preliminary review of the fishes of the family Scombridae — Bruce B. Collette and Robert H. Gibbs, Jr. 977-978

1B Comparative distribution of eggs, larvae and adults in relation to biotic and abiotic environmental factors — Hiroshi Yabe, Yoichi Yabuta and Shoji Ueyanagi 979-1009

2 Subpopulation identification — John C. Marr 1011-1021

3 Size and composition of tuna stocks — Johs. Hamre 1023-1039

4 The matter of availability and the harvest of tunas — Gerald V. Howard 1041-1055

5 Tuna behavior and physiology, a review — John J. Magnuson 1057-1066

6 Fishing techniques for tunas and skipjack — Shigene Takayama 1067-1076

7 Statistics of catch and effort required for scientific research on the tuna fisheries — Milner B. Schaefer 1077-1086

8 Future lines of tuna research, mainly in relation to fisheries oceanography — Michitaka Uda 1087-1095

9 World-wide tuna research planning — Wilbert McLeod Chapman 1097-1107

EXPERIENCE PAPERS

1 Preliminary experiments with tilapia as bait in the tuna fishery off the coast of Brazil — José Bonifácio Gomes da Fonseca 1109-1112

2 Investigation of tuna behavior by fish finder — Minoru Nishimura 1113-1123

3 Tuna tagging experiments in Norwegian waters — Johs. Hamre 1125-1132

4 Measurement of the shape of the tuna longline and an analysis of its efficiency — Chikamasa Hamuro 1133-1142

EXPERIENCE PAPERS (Continued) Page no.

5 Estudios sobre la reproducción del bonito *Sarda chilensis* (C. y V.) en aguas adyacentes a la costa Peruana — Aurora Chirinos de Vildoso 1143-1152

6 Tunas (genus *Thunnus*) of the western North Atlantic Part I. Key to the species of *Thunnus* based on skeletal and visceral anatomy — Margaret E. Watson 1153-1154

7 Tunas (genus *Thunnus*) of the western North Atlantic Part II. Description, comparison and identification of species of *Thunnus* based on external characters — Frank J. Mather, III 1155-1157

8 Tunas (genus *Thunnus*) of the western North Atlantic Part III. Distribution and behavior of *Thunnus* species — Frank J. Mather, III 1159-1161

9 An outline of the tuna longline grounds in the Indo-Pacific (preliminary report) — Akira Suda, Tsutomu Koto and Susumu Kume 1163-1176

10 Monofilament gill net fishing for skipjack tuna in Hawaiian waters (a progress report) — Richard S. Shomura 1177-1199

11 Climatic parameters and the Hawaiian skipjack fishery — Gunter R. Seckel 1201-1208

12 A method for computing estimates and variances of relative log fishing powers of California albacore vessels — Norman J. Abramson 1209-1215

13 The California albacore fishery logbook system — William L. Craig 1217-1225

14 Changes in availability of albacore in the eastern Pacific Ocean 1952 and 1958 — James H. Johnson 1227-1235

15 Structure of the albacore stock and fluctuation in the catch in the North Pacific areas — Akira Suda 1237-1277

16 Seasonal and annual variation of the hooking-rate and annual variation of the catch-quantity of tuna and marlin in the tropical Atlantic Ocean — J. Nakagome and S. Suzuki 1279-1297

EXPERIENCE PAPERS (Continued)

Page no.

17 Distribution of the yellowfin tuna *Neothunnus macropterus* (Temminck and Schlegel) in the tuna longline fishing grounds of the Pacific Ocean — Tadao Kamimura and Misao Honma 1299-1328

18 A review of the frigate mackerels (genus *Auxis*) of the world — John E. Fitch and Phil M. Roedel 1329-1342

19 Albacore scouting in the eastern North Pacific Ocean — Leo Pinkas 1343-1353

20 A method of sampling the Pacific albacore (*Thunnus germo*) catch for relative age composition — David J. Mackett 1355-1366

21 California's tuna record gathering system — Edward C. Greenhood 1367-1379

22 Studies of the erythrocyte antigens of albacore, bigeye, skipjack, and yellowfin tunas and their use in subpopulation identification — Lucian M. Sprague, James R. Holloway and Leslie I. Nakashima 1381-1393

23 Tuna landings and production 1916 to 1961 — Edward C. Greenhood and Sterling P. Davis 1395-1407

24 Growth and sexual dimorphism in growth of bigeye tuna (*Thunnus obesus*) a preliminary report — Richard S. Shomura and Betty Ann Keala 1409-1417

25 Schooling behavior within aggregations composed of yellowfin and skipjack tuna — Heeny S. H. Yuen 1419-1429

26 Food of skipjack in the central Pacific — Kenneth D. Waldron and Joseph E. King 1431-1457

27 Effects of water temperature on the distribution of some scombrid fishes along the Pacific coast of North America — John Radovich 1459-1475

28 Distribution of tuna species in the oceanic northwest Atlantic — James L. Squire, Jr. 1477-1514

29 A first examination of the abundance and distribution of yellowfin and albacore tuna in the western tropical Atlantic, 1957 to 1961 — Flavio Rodrigues Lima and John P. Wise 1515-1521

EXPERIENCE PAPERS (Continued)

Page no.

30 Food of Pacific albacore in the California fishery (1955 - 1961) Harold B. Clemens and Robert A. Iselin 1523-1535

31 A model of albacore migration in the North Pacific Ocean Harold B. Clemens 1537-1548

32 Especies del género *Sarda* en el Pacífico oriental Aurora Chirinos de Vildoso 1549-1556

33 Distribution and abundance of tuna related to wind and ocean conditions in the Gulf of Tehuantepec, Mexico Maurice Blackburn 1557-1582

34 Studies of oceanic fronts in the mouth of the Gulf of California an area of tuna migrations Raymond C. Griffiths 1583-1605

35 La pesquería del bonito en el Perú Felipe Ancieta 1607-1619

36 The olfactory organ of the skipjack *Katsuwonus pelamis* Reginald M. Gooding 1621-1631

37 The past, present and future status of the tuna resources of the trust territory of the Pacific Islands Peter T. Wilson 1633-1638

38 Thermal relationships of tuna in the oceanic northwest Atlantic James L. Squire, Jr. 1639-1657

39 Food of Indian tunas P.T. Thomas and M. Kumaran 1659-1667

40 Spawning of the oceanic skipjack *Katsuwonus pelamis* (Linnaeus) in the Laccadive Sea G. Raju 1669-1682

41 A contribution to the biology of Philippine tunas Inocencio A. Ronquillo 1683-1752

42 Distribution of larval tuna collected by the Carlsberg Foundation's *Dana* expedition (1928-30) from the Indian Ocean S. Jones and M. Kumaran 1753-1774

43 Tuna and tuna-like fishes from the Indian seas S. Jones and E. G. Silas 1775-1796

44 Description des stades post-larvaires et juvéniles de *Neothunnus albacora* (Lowe) de l'Atlantique tropico-oriental E. Marchal 1797-1811

EXPERIENCE PAPERS (Continued)

		Page no.
45	Resultados del programa de marcado de atún en aguas españolas — Julio Rodriguez-Roda	1813-1822
46	Talla, peso, edad y crecimiento del atún del Golfo de Cádiz, España — Julio Rodriguez-Roda	1823-1834
47	Distribution and relative abundance of tunas in relation to their environment — Taivo Laevastu and Horacio Rosa, Jr.	1835-1851

Methodological Paper No. 1A

A PRELIMINARY REVIEW OF THE FISHES[1] OF THE FAMILY SCOMBRIDAE

by

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Abstract

Tentatively, two subfamilies are recognized within the Scombridae: the Gasterochismatinae (which may perhaps have to be split off as a separate family) and the Scombrinae. Within the latter there are two major groups of genera, the more primitive ones (Scomber to Acanthocybium) which lack a bony caudal keel and have a caudal notch and the more advanced (Gymnosarda to Thunnus) which have a bony caudal keel and lack a caudal notch. Both these groups can be further split into smaller groups of genera: Scomber (about 2 species) and Rastrelliger (1 or 2 species); Scomberomorus (9 to 15 species) and the monotypic Grammatorcynus and Acanthocybium; Gymnosarda (1 or 2 species) and the monotypic Orcynopsis; Sarda (2 to 5 species); Auxis (probably 2 species); Euthynnus (2 to 5 species); the monotypic Allothunnus; and Thunnus (6 species).

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[1] The revised text of this paper was published in Volume 1 of the Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, to which the following addition should be made between 3. 7 Acanthocybium Gill and 3. 8 Orcynopsis Gill:

Cybiosarda Whitley

The only species in this genus, C. elegans (Whitley) has stripes below the lateral line suggesting Euthynnus pelamis but also has spots above the lateral line. Originally described as a subgenus of Scomberomorus, Fraser-Brunner (1950) synonymized it with Gymnosarda. The relationships of Cybiosarda with Orcynopsis, Gymnosarda, and Sarda demand further study.

ETUDE PRELIMINAIRE DES POISSONS DE LA FAMILLE DES SCOMBRIDAE

Résumé

On divise provisoirement les Scombridae en deux sous-familles: les Gasterochismatinae (qu'il faudra peut-être considérer comme une famille distincte) et les Scombrinae. On peut distinguer dans celle-ci deux groupes principaux: les genres les plus primitifs (*Scomber* à *Acanthocybium*), qui ne possèdent pas de carène osseuse sur le tronçon caudal, celui-ci étant échancré; et les plus développés (*Gymnosarda* à *Thunnus*), avec une carène osseuse de chaque côté de la caudale, qui est en croissant. Les divers genres composant ces deux groupes sont les suivants: *Scomber* (2 espèces environ) et *Rastrelliger* (1 ou 2 espèces); *Scomberomorus* (de 9 à 15 espèces), et *Grammatorcynus* et *Acanthocybium*, représentés chacun par une seule espèce; *Gymnosarda* (1 ou 2 espèces) et *Orcynopsis*, monotypique; *Sarda* (de 2 à 5 espèces); *Auxis* (probablement 2 espèces); *Euthynnus* (de 2 à 5 espèces); *Allothunnus*, monotypique; et *Thunnus* (6 espèces).

UN ESTUDIO PRELIMINAR DE LOS PECES DE LA FAMILIA SCOMBRIDAE

Resumen

Se reconocen en forma tentativa dos subfamilias dentro de los Scombridae: Gasterochismatinae (que quizá tenga que ser descompuesta en una familia independiente) y Scombrinae. Dentro de esta última hay dos grupos principales de géneros: los más primitivos (*Scomber* a *Acanthocybium*) que carecen de quilla caudal ósea y que tienen una escotadura caudal, y los más avanzados (*Gymnosarda* a *Thunnus*) que tienen quilla caudal ósea y carecen de escotadura caudal. Ambos grupos pueden ser subdivididos a su vez en grupos más pequeños de géneros: *Scomber* (unas dos especies) y *Rastrelliger* (1 a 2 especies); *Scomberomorus* (9 a 15 especies) y el monotípico *Grammatorcynus* y *Acanthocybium*; *Gymnosarda* (1 a 2 especies) y el monotípico *Orcynopsis*; *Sarda* (2 a 5 especies); *Auxis* (probablemente 2 especies); *Euthynnus* (2 a 5 especies); el monotípico *Allothunnus* y *Thunnus* (6 especies).

Methodological Paper No. 1B

COMPARATIVE DISTRIBUTION OF EGGS, LARVAE AND ADULTS IN RELATION TO BIOTIC AND ABIOTIC ENVIRONMENTAL FACTORS

By

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Abstract

The geographical distribution of various species of tuna is given. Knowledge of distribution has accumulated through various types of fisheries, such as trap net, purse-seine, trolling, pole-and-line and longline in coastal and adjacent waters, and mainly through the longline fishery in pelagic waters. Since the fisheries do not cover the entire area of distribution of tuna, especially in pelagic waters, the quantity and quality of available information are not uniform for different species and areas. Information is most abundant for the Pacific, followed by the Indian and Atlantic Oceans.

Information on the vertical distribution of adult tuna has been determined from the catch by various types of gear. Research indicates that tunas occur in the relatively upper layers of the ocean and that vertical distribution varies according to the species, with skipjack, bluefin, yellowfin, bigeye and albacore living in deeper waters, in that order. Juveniles appear partly in the same vertical distribution, though there is indication that they may prefer shallower depths.

Environmental factors having a bearing on distribution, such as water temperature, salinity, transparency, current system and water type, and productivity, are discussed. However, present knowledge is not sufficient for understanding the distribution pattern of each species in terms of environmental factors, both biotic and abiotic.

Information on larval and young life of tunas, before they become vulnerable to fisheries, is far less available than for adults. The most data has been assembled for yellowfin and skipjack. Investigation of juveniles is particularly hampered by difficulties in their collection.

MP/1B

REPARTITION DES OEUFS, LARVES ET ADULTES EN FONCTION DES FACTEURS BIOTIQUES ET ABIOTIQUES DU MILIEU

Résumé

La communication indique la distribution géographique de diverses espèces de thons. Les connaissances actuelles sur la répartition de ces poissons ont été fournies par les résultats de diverses méthodes de pêche: madragues, sennes tournantes, lignes de traîne, canne et hameçon, palangres, dans les eaux côtières et les eaux peu éloignées et surtout pêche aux palangres dans les eaux pélagiques. Du fait que, particulièrement dans ces eaux, la pêche ne s'exerce pas sur la totalité de la zone fréquentée par les thons, les renseignements recueillis presentent des différences, tant en quantité qu'en qualité, selon les espèces et les lieux de pêche. Les régions pour lesquelles on dispose de très nombreux renseignements sont, par ordre décroissant, l'océan Pacifique, l'océan Indien et l'océan Atlantique.

Les données sur la répartition en profondeur des thons adultes ont été obtenues à partir des prises effectuées par divers types d'engins. La recherche a permis de constater que les thons se déplacent dans les eaux relativement proches de la surface, la distribution en profondeur variant selon l'espèce. Par ordre de profondeur croissante, on trouve les habitats des espèces suivantes: bonite à ventre rayé, thon rouge, thon à nageoires jaunes, thon obèse et germon. Les immatures présentent en partie la même répartition verticale, que d'après certains indices, ils paraissent préférer les couches moins profondes.

Le document examine les facteurs environnants exerçant une influence sur la répartition: température de l'eau, salinité, transparence, régime des courants et type d'eau, ainsi que la productivité. Toutefois, les connaissances actuelles ne permettent pas d'expliquer le schéma de répartition de chaque espèce en fonction des facteurs ambiants, tant biotiques qu'abiotiques.

Les renseignements sur les stades larvaires et immatures des thons, avant qu'ils ne deviennent vulnérables aux engins de pêche, sont beaucoup plus rares que pour les adultes. C'est sur le thon à nageoires jaunes et la bonite à ventre rayé que l'on a réuni le plus de données. L'étude des stades immatures se ressent particulièrement des difficultés que présente leur prélèvement.

DISTRIBUCION COMPARATIVA DE HUEVOS, LARVAS Y EJEMPLARES ADULTOS EN RELACION CON LOS FACTORES AMBIENTALES BIOTICOS Y ABIOTICOS

Extracto

Se expone la distribución geográfica de las diversas especies de atún, sobre la cual se han allegado conocimientos gracias a varios métodos de pesca, tales como la captura con trampas, cercos de jareta, curricanes, caña y línea y palangres en aguas costeras y contiguas, y, especialmente, con palangres en aguas pelágicas. Dado que las pesquerías no abarcan toda el área de distribución del atún, especialmente en aguas pelágicas, la cantidad y calidad de la información disponible no es uniforme para las diferentes especies y zonas. La información más abundante es la correspondiente al Pacífico, seguida por las de los océanos Indico y Atlántico.

Los datos de la distribución vertical del atún adulto han sido colegidos de capturas efectuadas con varios tipos de artes y aparejos. La investigación denota que el atún se presenta en estratos oceánicos relativamente superiores, y que su distribución vertical varía según especies, siendo el barrilete, el atún de aleta azul, el de aleta amarilla, el patudo y la albacora, en este orden, los que viven en aguas más profundas. Los ejemplares juveniles se presentan, parcialmente, en igual distribución vertical, aunque hay indicios de que prefieren aguas más someras.

Se exponen los factores ambientales que influyen en la distribución como, por ejemplo, la temperatura del agua, su salinidad, transparencia y tipo, los sistemas de corrientes y la productividad. Sin embargo, los conocimientos actuales no bastan para interpretar el régimen de distribución de cada especie en función de los factores ambientales, sean éstos bióticos o abióticos.

La información sobre estados larvarios y formas juveniles, antes de que sean vulnerables a la pesca, es mucho menor que la relativa a los peces adultos. La mayoría de los datos han sido tomados de atunes de aleta amarilla y de barriletes. La investigación de las formas juveniles se ve entorpecida singularmente por las dificultades para recolectarlas.

1 INTRODUCTION

The distribution of tunas extends over a vast expanse of the ocean in the tropical, subtropical, and temperate zones. Tunas, with some exceptions, are great migrants throughout their life span.

Knowledge of their distribution has been accumulated through various types of fisheries, such as trap net, purse seine, trolling, pole and line, longline, etc., in coastal and adjacent waters, and mainly through longline fisheries in the pelagic waters. Since the existing fisheries have not developed sufficiently to cover the entire area of distribution of the tunas, especially in pelagic waters, the quantity and quality of available information are not uniform for different species and areas. Information is most abundant for the Pacific, followed by the Indian and Atlantic Oceans in this order. Despite these restrictions, the general distribution pattern for adults of each species has been established.

The effects of various environmental factors upon the distribution of tunas have also been demonstrated in certain area. Tuna abundance in the temperate zone is related to water temperature and to specific oceanographic conditions in the contact area between warm and cold water masses. Their distribution in equatorial waters is related to high basic productivity resulting from upwelling and divergence. It is to be noted, however, that present knowledge is not sufficient to understand the distribution pattern of each species in terms of environmental factors, both biotic and abiotic.

Information on the larval and young life of tunas before they become vulnerable to fisheries is far less available because of the difficulties of specific identification. Except for yellowfin and skipjack, there is no substantial information on their distribution, nor on the effects of environmental factors. The investigation on juveniles has been particularly hampered by difficulties in their collection.

2 GEOGRAPHICAL DISTRIBUTION

2.1 Adults

The geographical distribution of tunas is presented in Figs. 1 to 9, which were modified from the figures by Rosa and Laevastu (1961) by addition of data collected by Japanese commercial and research fishing boats. These figures are constructed on the basis of the present status of tuna fisheries. Information is lacking except for the areas designated in the above figures as "fishing area". Hence, the peripheral portions of the areas are most likely to be modified with the further development of the fisheries. The above mentioned paper and the "average year's fishing condition of tuna long-line fisheries, 1958" are the main sources for the following description.

2.1.1 Yellowfin tunas (Fig. 1)

Neothunnus macropterus

Pacific Ocean: The distribution of this species extends from 40° N to 30°S, but it is most abundant along the Equator, or between 10°N and 10°S. Fig. 2 shows the distribution of the observed hooking rates between 170°E and 180°. The hooking rate, or number of fish caught per 100 hooks, is generally accepted as a measure of the abundance of the fish.

The hooking rate, as is apparent in Fig. 2, is highest in the equatorial waters, decreasing sharply towards north and gradually towards south.

In the waters where warm currents, such as the Kuroshio and East Australian Currents dominate considerably higher concentrations occur seasonally in the higher latitude waters.

The hooking rates do not show any definite trend in variation in an east-west direction.

Seasonal change in the distribution is not very large. In the western Pacific the abundance is higher between November and March and in the eastern Pacific between 170°W and 150°W in May and June.

There is a longitudinal change in body length with larger fish being caught towards east. It is also reported that smaller fish are more abundant close to islands even in the mid-ocean waters (Shomura and Murphy 1955; Kamimura and Honma 1961).

Indian Ocean: Yellowfin are found north of

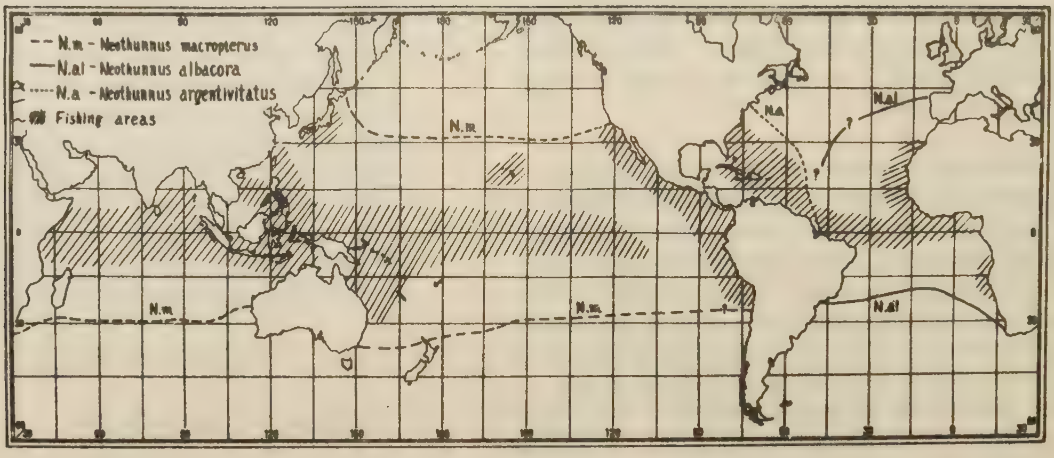
-- N.m - Neothunnus macropterus
— N.al - Neothunnus albacora
..... N.a - Neothunnus argentivitatus
Fishing areas
N.m
N.a
N.al
N.m
N.m
N.al

Fig. 1 Distribution of yellowfin tunas.

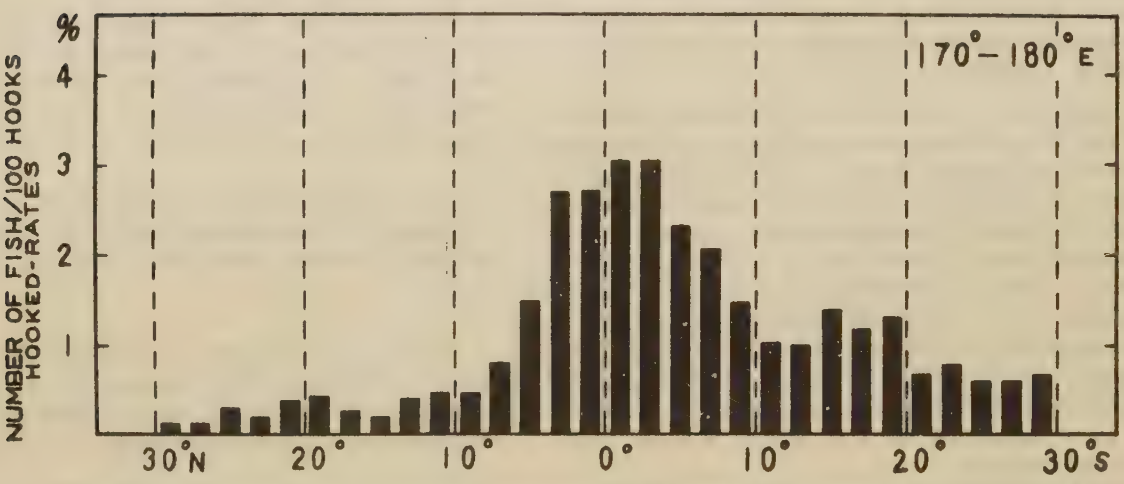

Fig. 2 Latitudinal catch-rates (number of fish per 100 hooks) of yellowfin tuna.

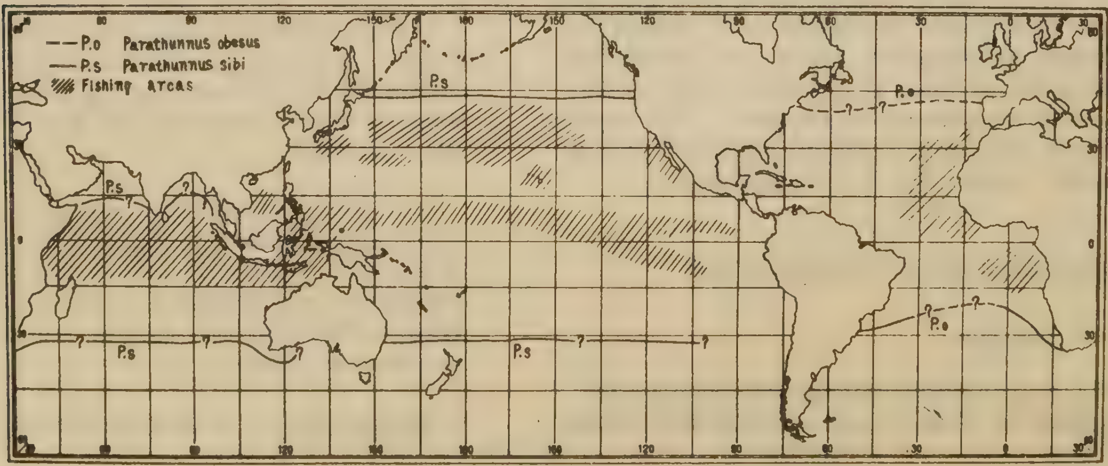
--- P.o Parathunnus obesus
— P.s Parathunnus sibi
Fishing areas
P.s
P.o
P.s
P.s
P.s
P.o

Fig. 3 Distribution of bigeye tunas.

about 30°S, abundant between 10°S and 10°N, and very sparse south of 10°S.

The abundance of yellowfin varies by area and season even in the waters between 10°S and 10°N where they are relatively abundant throughout the year. They are more abundant between January and June, and sparse between July and December.

In the Gulf of Bengal and the Arabian Sea, the abundance is higher between March and June, but information is generally lacking for the rest of the year.

Considerable concentration, especially from November to January, is also reported in the Banda, Flores Seas and waters around the Sunda Islands in the extreme east of the Indian Ocean.

N. albacora

Atlantic Ocean: Occasionally recorded on the coast of Spain and Portugal, along the whole of the west coast of Africa, between 0° and 10°N on the east coast of South America, and across the Atlantic Ocean. In the equatorial region it is especially abundant.

N. argentivitatus

Atlantic Ocean: Northwest Atlantic coast of the United States and Caribbean Sea.

It must be re-examined whether N. argentivitatus and N. albacora belong to the same species.

2.1.2 Bigeye tunas (Fig. 3)

Parathunnus sibi

Pacific Ocean: Occur between 45°N and 35°S with two high concentration areas, each extending in an east-west direction, one between 25°N and 40°N and the other between 6°N and 12°N. These high concentration areas are known to Japanese fishermen as the "Northern" and "Equatorial Fishing Grounds" respectively.

The abundance in the two areas increases to the east, especially east of 180°.

In the Northern Fishing Ground, the abundance is high between October and February and low between March and June. Size of the fish in this particular area ranges from 60 to 200 cm, increasing to the east.

In the Equatorial Fishing Ground, the center of distribution lies between 6°N and 12°N west of 150°W. East of 150°W, the center shifts slightly to the South, and east of 130°W it splits into two parts, one to the north and the other to the south. The shift and split in the concentration area in the eastern Equatorial Pacific appear to be related to upwelling in the equatorial waters.

Size of the fish in this area range from 50 to 200 cm, with the majority being 90 to 170 cm. Fish become larger towards the east, and only large fish over 120 cm are found east of 150°W.

Indian Ocean: Occur north of about 30°S.

Abundance is higher between 10°S and 10°N, and peaks occur in two areas, one bounded by 0°, 10°S, 90°E and 110°E, and the other by 0°, 10°N, 50°E, and 70°E. General abundance is much lower however than for yellowfin. Seasonal variation in the abundance is not clearly understood, but the abundance increases around September in the water bounded between 0° and 10°S and between 90°E and 100°E. The fish are particularly abundant close to the coast.

P. obesus

Atlantic Ocean: Portugal and Spain, where it is rarely caught, and along the West African coast as far south as the Union of South Africa. Between 0° and 10°N along the coast of South America and across the Atlantic Ocean.

As a result of the fishing activities of Japanese commercial and research fishing vessels, the distribution has been described in the Caribbean Sea and off Brazil. Its abundance in the Atlantic, as in the Pacific, increases from west to east.

2.1.3 Albacore (Fig. 4)

Germo alalunga

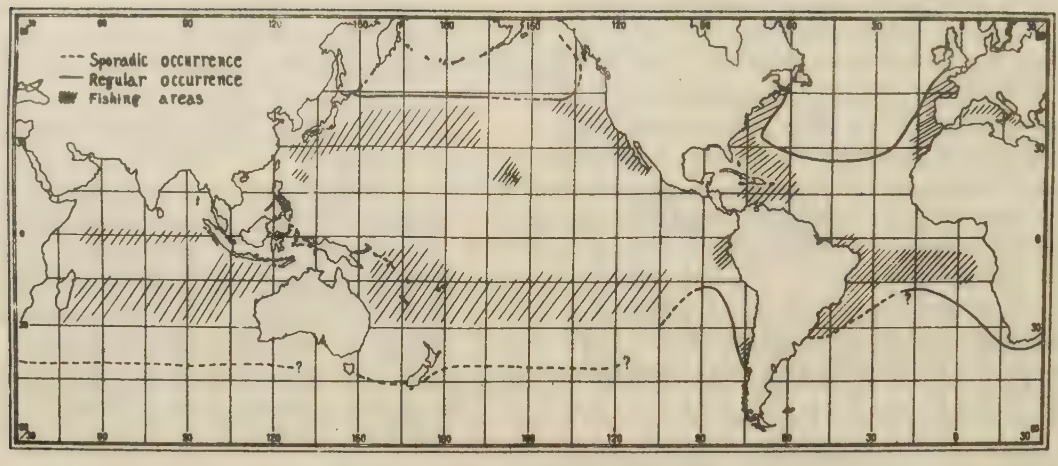
--- Sporadic occurrence
— Regular occurrence
Fishing areas
?

Fig. 4 Distribution of albacore.

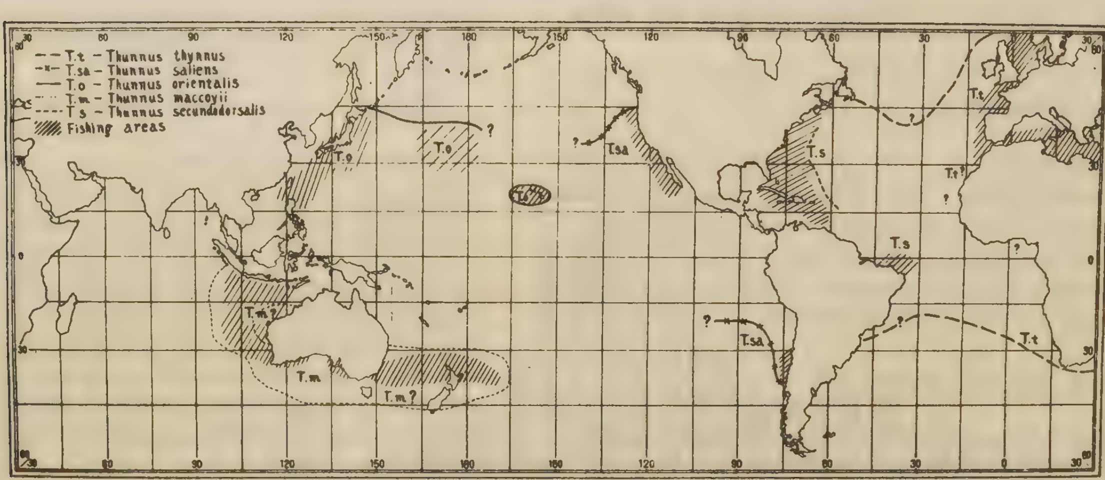
-- T.t - Thunnus thynnus
-x- T.sa - Thunnus saliens
— T.o - Thunnus orientalis
T.m - Thunnus maccoyii
---- T.s - Thunnus secundodorsalis
Fishing areas
T.o
T.o
T.sa
T.s
T.t
T.t?
T.s
T.m?
T.m
T.m?
T.sa
T.t

Fig. 5 Distribution of bluefin tunas.

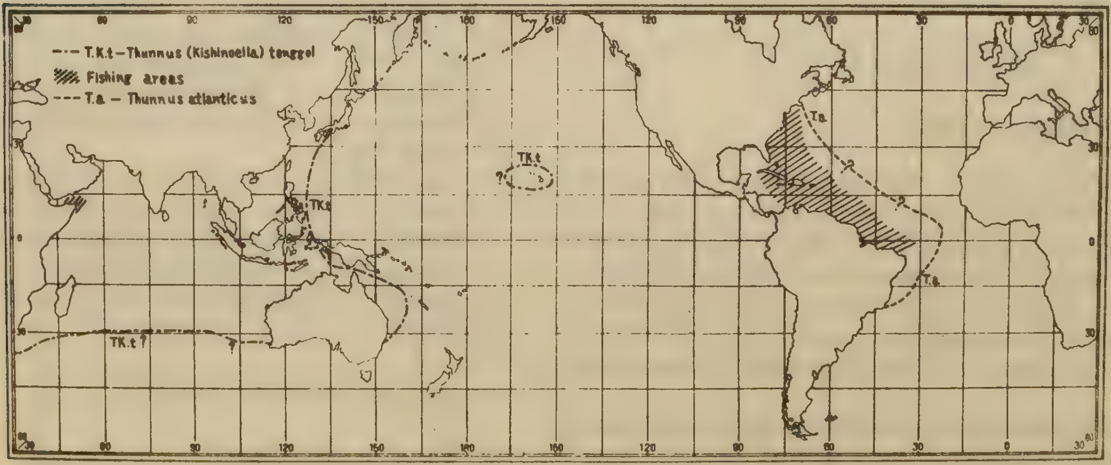
-.- T.K.t - Thunnus (Kishinoella) tonggol
Fishing areas
--- T.a - Thunnus atlanticus
T.a
TK.t
TK.t
TK.t ?
T.a

Fig. 6 Distribution of Thunnus tonggol (Indo-Pacific) and blackfin tuna T. atlanticus (Atlantic).

Pacific Ocean: There are two areas of high abundance, one extending from 25°N to the Polar Front and the other from 5°S to 30° S. It occurs sporadically from 25°N to 10°N, but virtually no fish are found in the equatorial zone between 10°N to 5°S. Thus, the populations in the North and South Pacific are separated from each other. This conclusion is supported by the location of their spawning areas and the distribution of juveniles.

In the North Pacific, albacore are abundant north of the Subtropical Convergence at approximately 25°N.

The fishing grounds shift with the season. From October to March, longline fishing is conducted in waters between 25°N and 40°N latitude, and 130°E and 170°W longitude. From April to July, the albacore approach Japan and are caught by angling; from July to September they become vulnerable to trolling and live-bait fisheries off California. Albacore on the above fishing grounds are mostly immature fish 3 and 4 years old. Mature fish over 5 or 6 years old are distributed to the south of the Sub-tropical Convergence in the northern Equatorial waters.

In the South Pacific, high concentrations continue throughout the year between 10°S and 30°S, and from April to June the fringe of the high abundance area extends northwards to 4°S.

Albacore, found in the above waters, are mostly mature and 5 to 7 years old (Uchida and Otsu, 1961).

Information is lacking south of 30°S, where there is no fishing activity, but young albacore are most likely to be found in this area.

Indian Ocean: The distribution is virtually limited to the waters south of the Equator. They are abundant between 10°S and 30°S throughout the year and are also found between 0° and 10°S from April to September. The eastern boundary of their main occurrence is subject to seasonal variation. Between April and September it extends to approximately 120°E and between October and March to approximately 110°E. Fish available in these waters are mostly of higher aged groups.

It is presumed that the distribution continues to extend southwards beyond 30°S where there is no fishing activity.

Atlantic Ocean: It is known that the distribution is confined between approximately 50°N and approximately 40°S. As a result of the recent development of fisheries in this area, two independent areas of high abundance have been found north and south of the Equatorial waters, where abundance is extremely low. Abundance is particularly high south of 5°S. The southern extreme of their occurrence is not known yet.

2.1.4 Bluefin tunas (Fig. 5)

Thunnus thynnus

Atlantic Ocean: Latitude 70°N in the Eastern North Atlantic, found abundantly from about the southern coast of Norway to Morocco, including the Mediterranean and Black Seas. Recorded in the Canary Islands, Spanish West Africa and Angola, but the distribution in West Africa is not yet defined.

T. secundodorsalis

Atlantic Ocean: Nova Scotia, Canada, southward to Caribbean Sea, and northeast of Brazil.

A fish tagged and released off Cape Cod, Massachusetts, U. S. A., was recaptured in the Bay of Biscay located at the opposite side of the Atlantic Ocean, after a 5-year interval (Mather III and Schuck, 1960). This evidence suggests that the taxonomy of *T. secundodorsalis* and *T. thynnus* must be re-examined.

T. orientalis

Western North Pacific: Coastal and high seas of Japan as far north as Sakhalin Islands; south to 15°N off the coast of Luzon, Philippines; occasionally caught in Hawaii.

T. saliens

Eastern Pacific: Columbia River in the United States, to Cape San Lucas in Mexico. Rarely in central Chilean waters.

Because T. orientalis are caught not only in the waters around Japan but east of Hawaii, it is very probable that they are distributed across the entire Pacific. Therefore, re-examination of the taxonomic basis of T. orientalis is needed in terms of T. saliens, found off California.

T. maccoyii

Indo-Pacific: Southern waters of Australia, New Zealand, Indonesia.

2.1.5 Blackfin tuna (Fig. 6)

Thunnus atlanticus

Atlantic Ocean: North of Maryland in the United States, south to and including the Caribbean Sea.

2.1.6 Northern bluefin (Koshinaga) (Fig. 6)

Thunnus (Kishinoella) tonggol

Indo-Pacific: Widespread in the Indian Ocean, Cape Town to Natal, South Africa; Somalia, Gulf of Aden, India, Ceylon, Indonesia, Malaya, Philippines, southern Japan, Formosa, northern and western waters of Australia; Hawaii.

2.1.7 Skipjack (Fig. 7)

Katsuwonus pelamis

Caught in coastal areas and on current boundaries. Seems to have separate populations in different areas, where they appear to be associated with certain island groups.

Rarely found as far north as Vancouver Island, Canada. Commercially caught off the Pacific coast of the Americas from about latitude 32°N 20°S; spans the Pacific Ocean from Hawaii to the western Pacific. Caught by Japanese boats from about latitude 40°N to 30°S and around longitude 115°E to 150°W. Widespread in the Indian Ocean; seen throughout the year in East Africa and caught in Madagascar and Northern Somalia.

In the Atlantic Ocean from the British Islands, where it is occasionally caught, south to about the Equator, including the Mediterranean. In the Americas occasionally caught as far north as Cape Cod; becomes abundant from the southern coast of the United States through the Caribbean as far south as Brazil.

2.1.8 Bonitos (Fig. 8)

Caught relatively close to the coast.

Sarda sarda

In Europe rarely caught north of France, but rather abundant from Spain as far south as the Equator including the Mediterranean Sea. Intensively caught in the Black Sea. On the American coasts from Nova Scotia to Argentina including the Caribbean Sea.

S. chiliensis

Vancouver Island, Canada, to Central Chile.

S. orientalis

Widely distributed in the Indian Ocean and western Pacific from New Zealand and waters north to Japan.

2.1.9 Little tunas (Fig. 9)

Found mainly in coastal waters.

Euthynnus alletteratus

Coast of Norway where it is occasionally caught, south along the coast of West Africa as far as the Union of South Africa. Cape Cod, in the United States, to Argentina. Also occurs in the Mediterranean and Caribbean Seas.

E. lineatus

Off Mexico and Central America.

E. affinis

Widespread in the Indian and western Pacific Oceans as far north as southern Japan.

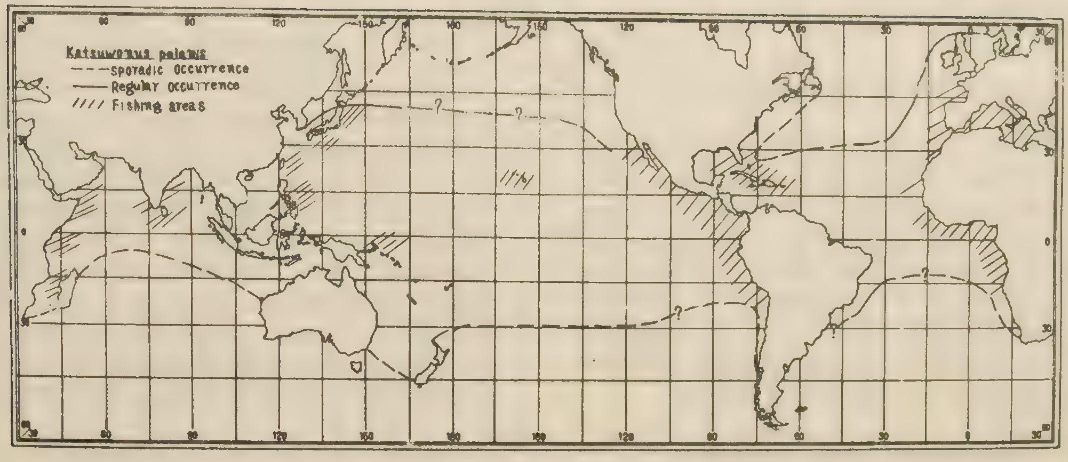
Katsuwonus pelamis
---sporadic occurrence
——Regular occurrence
//// Fishing areas
?

Fig. 7 Distribution of skipjack.

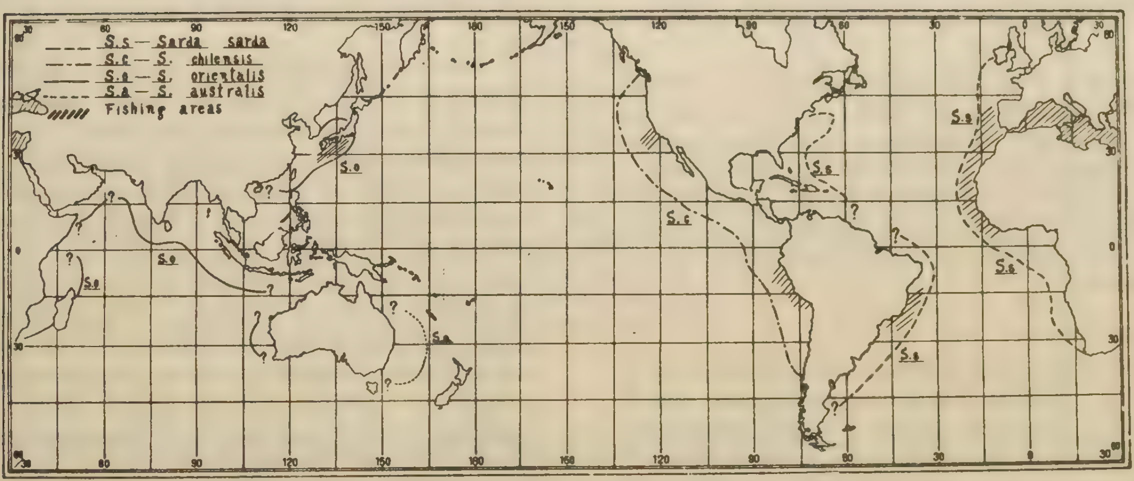
S.s — Sarda sarda
S.c — S. chilensis
S.o — S. orientalis
S.a — S. australis
Fishing areas
S.o
S.c
S.s
S.a
?

Fig. 8 Distribution of bonitos.

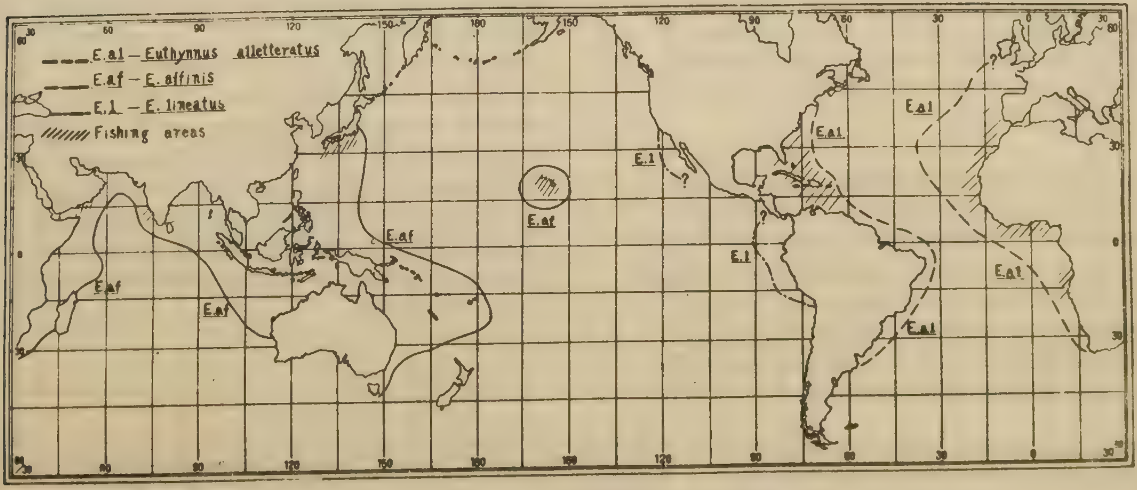
E.al — Euthynnus alletteratus
E.af — E. affinis
E.l — E. lineatus
Fishing areas
E.af
E.l
E.al
?

Fig. 9 Distribution of little tunas.

2.1.10 Frigate mackerels

Auxis thazard and A. tapeinosoma

Found in the Pacific, Atlantic, and Indian Oceans, and are, like little tunas, most abundant close to land masses. Though there are two species (A. thazard and A. tapeinosoma), their distribution cannot be separated from each other, because of the difficulties involved in their specific discrimination. In Japanese waters it is presumed that A. thazard extends farther southward than A. tapeinosoma.

2.1.11 Juveniles (Fig. 10 to 12)

Juveniles have been collected by means of midwater trawls (King and Iversen, 1961), but not successfully from the quantitative view point.

However, since juvenile tunas, 10 to 20 cm in length, are frequently found in the stomachs of adult tunas and spearfishes caught by longlines (Yabuta 1953; Suda 1953; Watanabe 1958; Yabe et al, 1958), considerable information on the distribution of juveniles has been collected through the analyses of stomach contents of these species.

Figures 10 to 12 show the occurrence of juveniles, which accords very well with that of larvae. In other words, frigate mackerel occur mostly in the waters not distant from islands, while skipjack, albacore, yellowfin, bigeye, etc. are quite trans-oceanic in their distribution in the sub-tropical and tropical waters. More specifically, albacore are found in the waters around 20° in latitude in the Pacific and Indian Oceans, and yellowfin and bigeye, on the other hand, in the waters between 10°S and 10°N.

In summary, the distribution of juvenile tunas, as well as their larvae, is generally confined to waters within 30° north and south of the Equator. Bluefin, albacore and bigeye migrate great distances outside the area of their growth from juvenile to immature and adult, but yellowfin tend to stay all their life in sub-tropical and tropical waters.

2.1.12 Eggs and larvae (Fig. 13 to 18)

From observations made on running ripe ova, the egg of tunas has a large oil globule and is supposed to be pelagic. The diameter of the ripe eggs is estimated to be around 1 mm. Sanzo (1932a) obtained developing eggs of bonito by artificial fertilization, and Kikawa (1953) and Kume (1962) also fertilized the eggs of bigeye artificially. Since they have not been actually collected in the sea, however, except in the cases mentioned below, no information is available on their oceanic distribution.

Sanzo (1932b, 1933) estimated the total length of newly-hatched larvae of Orcynus thynnus and O. germo [1] to be 2.44 to 3.04 mm. these larvae were obtained from eggs collected in plankton net hauls.

The distribution of tuna larvae, approximately 3 mm to 20 mm in length, is fairly known from the results of plankton net towing and night-light collecting by dipnetting. Figures 13 to 18 illustrate the localities of capture of tuna larvae. From these charts it may be concluded that larvae occur in the sub-tropical and tropical waters of the Pacific, Atlantic and Indian Oceans. Their distribution appears to be limited to within 30° latitude of the Equator, except where warm currents dominate. Where the Kuroshio, East Australian currents and Gulf Stream dominate, their distribution extends farther to the north.

The east-west distribution is trans-oceanic, but not uniform over the entire width of the ocean. The pattern differs by species, which will be considered later. It varies seasonally too, and in the waters higher than 20° in latitude, abundance peaks in summer. In waters along the Equator, on the other hand, the abundance varies little throughout the year (Matsumoto 1958; Yabe and Ueyanagi 1961). In summary, the distribution pattern of larvae agrees very well with that of juveniles. The characteristics of their occurrence by species are as follows:

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[1] Matsumoto (1958) presumed that the O. thynnus larvae were bluefin and the O. germo larvae were either yellowfin or albacore.

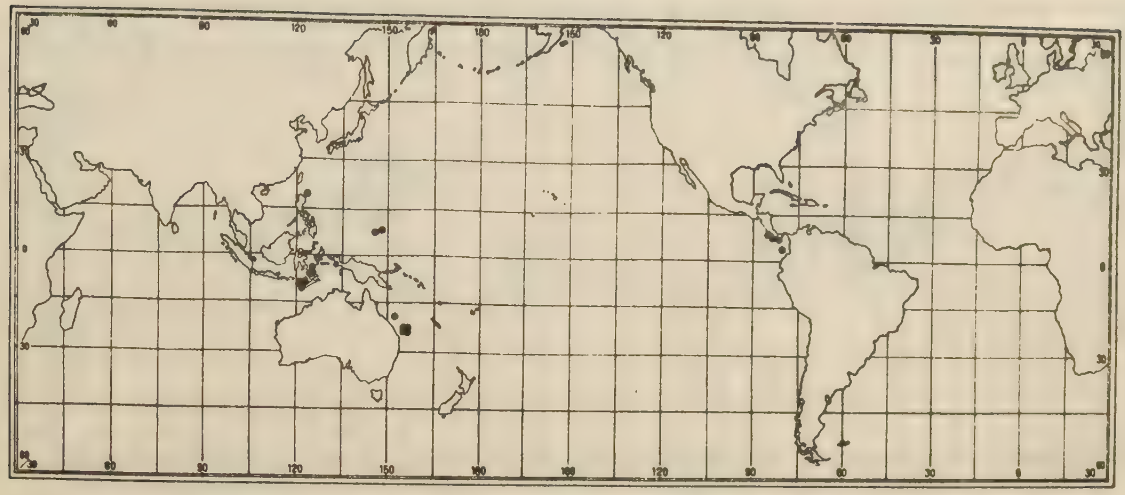

Fig. 10 Localities of capture of juvenile frigate mackerel.

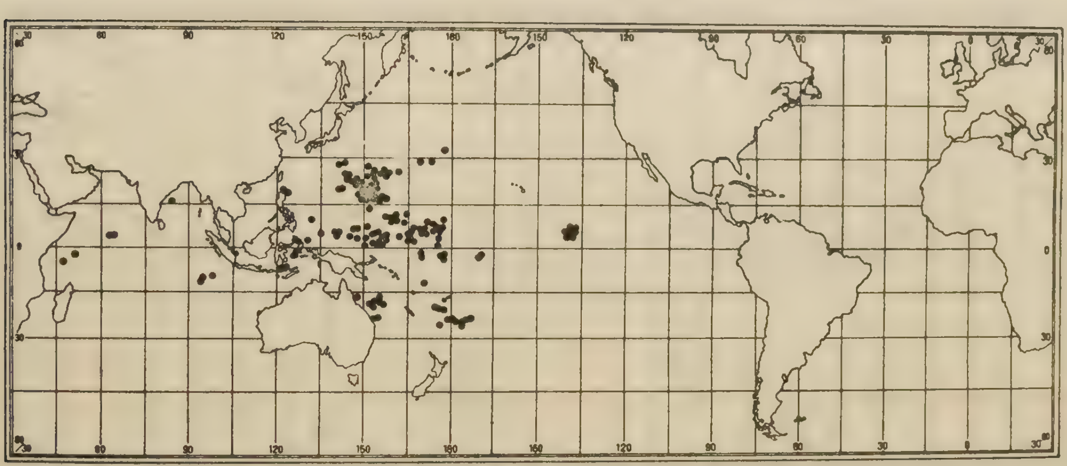

Fig. 11 Localities of capture of juvenile skipjack.

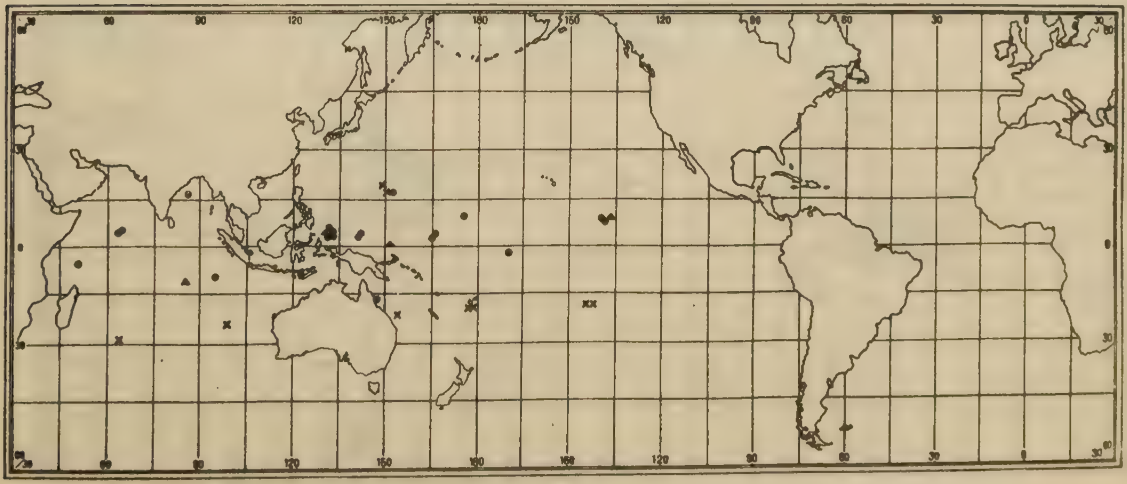

Fig. 12 Localities of capture of juvenile tunas.
X. . . albacore, black dots . . . yellowfin
black triangles . . . bigeye.

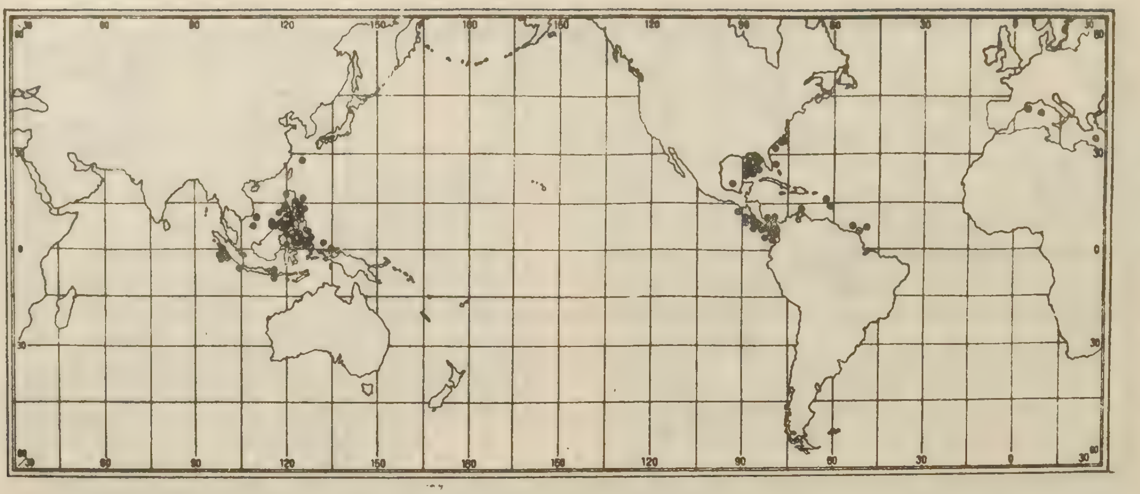

Fig. 13 Localities of capture of larvae of little tunas.

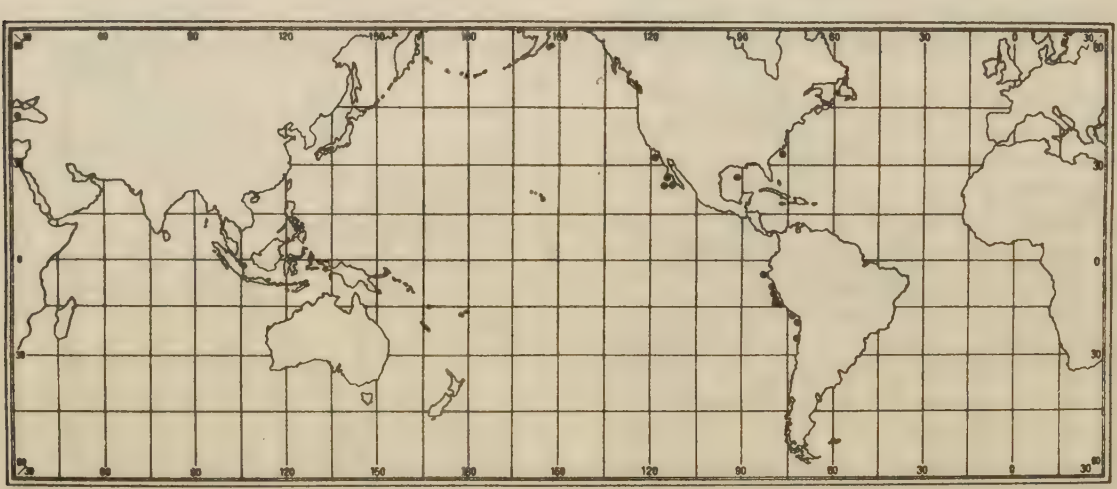

Fig. 14 Localities of capture of bonito larvae.

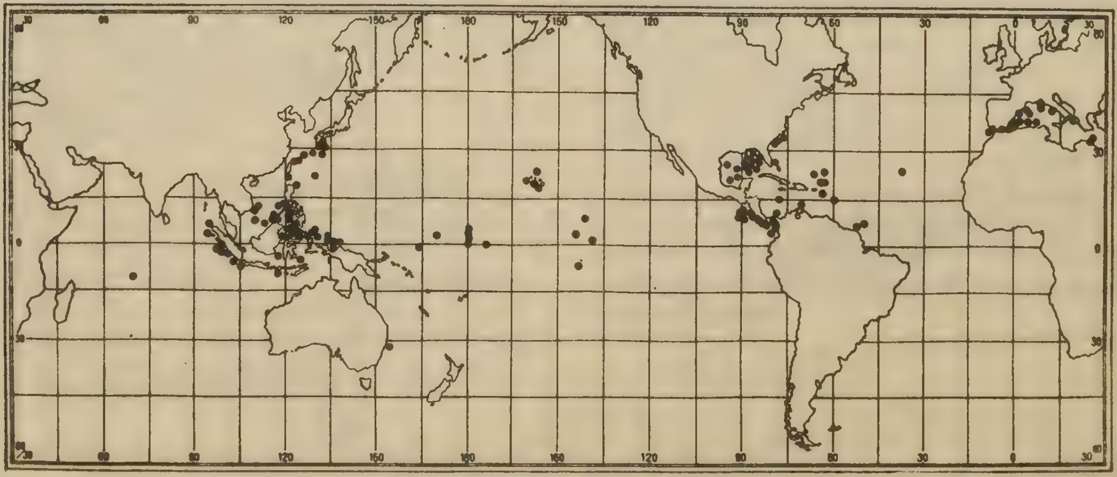

Fig. 15 Localities of capture of frigate mackerel larvae.

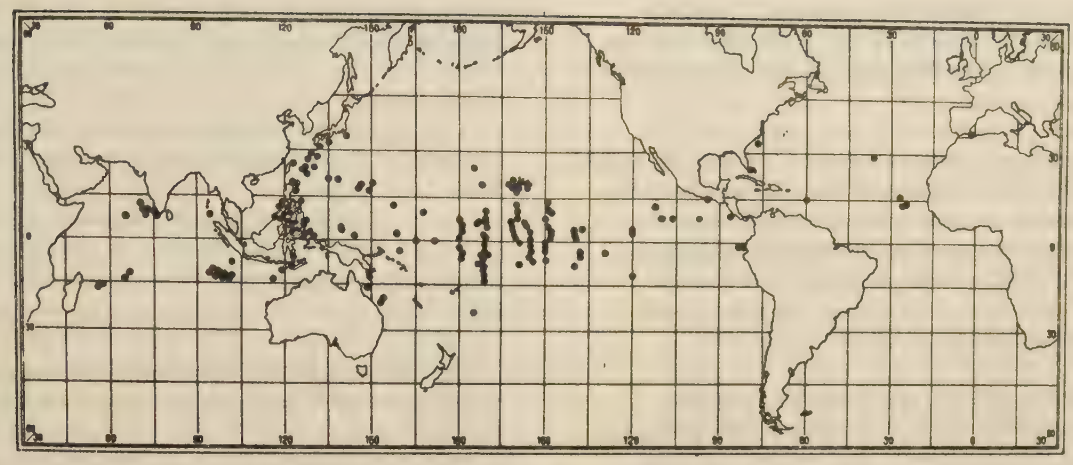

Fig. 16 Localities of capture of skipjack larvae.

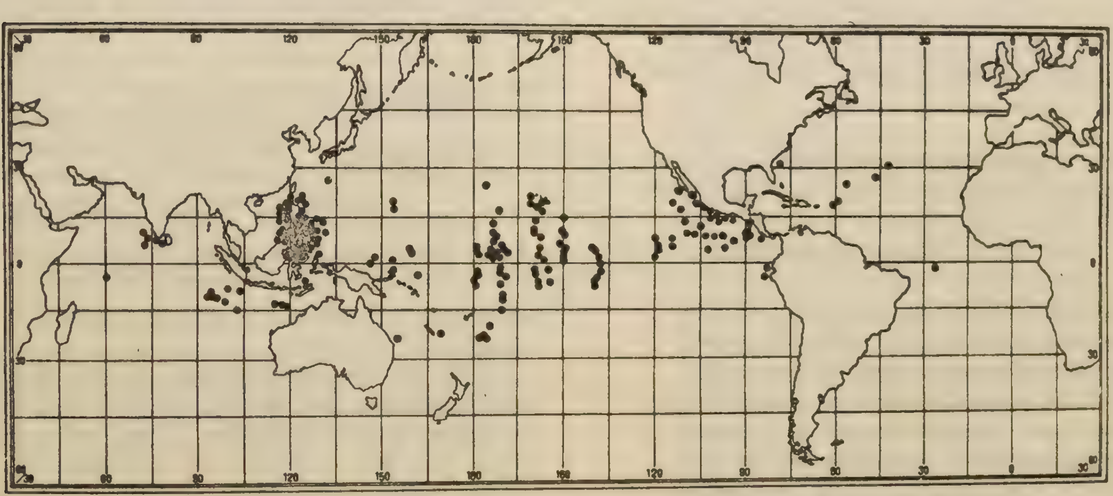

Fig. 17 Localities of capture of yellowfin larvae.

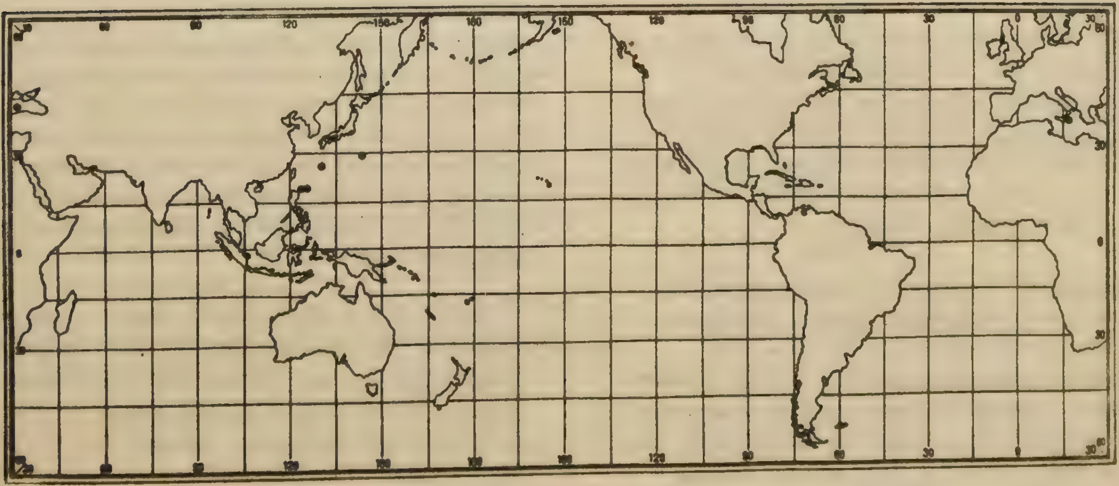

Fig. 18 Localities of capture of bluefin larvae.

Little tuna (larvae) are found in waters closest to land masses of all tuna species, as in the case of juveniles and adults (Matsumoto 1959).

Information on bonito is very scarce, except along the Pacific coasts of the American Continents, where it is reported they share the same coastal areas with the adults and juveniles (Klawe 1961). Occurrence of bonito larvae is reported also from the Black Sea (Vodyanitsky 1936).

Frigate mackerel are presumed to be most abundant in waters close to land masses, but are also found far distant from the land (Matsumoto 1959; Yabe and Ueyanagi, 1961).

Quite contrary to the above species, larvae of the following tunas are quite oceanic in their distribution and affected by the current systems:

Larvae of skipjack and yellowfin are trans-oceanic in distribution, but limited to the sub-tropical and tropical waters where the North and South Equatorial and Equatorial Counter Currents dominate. Variations in their occurrence in the above waters have been reported by Matsumoto (1958), who surveyed the waters bounded between 180° and 120°W in longitude and between 23°N and 15°S in latitude. According to his observation, skipjack were most abundant between 4°S and 5°N, whereas yellowfin were more plentiful around 5°S and 5°N and of lower abundance in between. Longitudinally, both species were less abundant east of 140°W.

Bluefin larvae (T. orientalis) are of greatest abundance in the waters where the Kuroshio Current originates (Matsumoto 1961; Yabe and Ueyanagi, 1961). Distribution of bluefin larvae in the Mediterranean and Black Seas has also been reported (Watson and Mather III, 1961; Vodyanitsky 1936).

Identification of albacore under about 15 mm has not yet been established. However, presumably larvae of albacore have been collected in areas supposed to be their spawning ground. These larvae seem to be concentrated in the waters around 20° latitude in the North and South Pacific, and Indian Ocean. Their presumed areas of main occurrence are, therefore, located in the North Equatorial Current of the North Pacific, and in the South Equatorial Current close to the Tropical Convergence in the South Pacific and Indian Oceans. This distribution is quite different from that of yellowfin larvae. Albacore larvae, ranging from 15 to 40 mm in length, are also found in the Straits of Messina of the Mediterranean Sea (Watson and Mather III, 1961).

Matsumoto (1961) reported the occurrence of larvae which he presumed to be bigeye, in the East Indies and western Pacific area. Further information of their distribution is scanty; it is very likely, however, that their main areas of occurrence are confined within 10° north and south of the Equator.

3 VERTICAL DISTRIBUTION

3.1 Adults

Information on the vertical distribution of adult tunas has been determined from the catch by various gears, such as longline, trolling, pole and line, purse seine, etc.

The vertical distribution can be estimated by comparing the hooking rate of longline hooks at different depths. The depth of each hook has been computed by various workers on the basis of the shape of the gear in the water (Yoshihara 1951, 1952; Murphy and Shomura 1953; Nakagome 1958, 1961). Results of the computation are further improved by direct measuring of the depth of hooks at an appropriate interval by use of depth meters and chemical or sounding tubes (Murphy and Shomura, 1955; Hamuro and Ishii, 1958). However, this kind of gear has two major defects; the water below some 160 m is beyond the reach of this gear, and the precise depth of the hooks at the time the fish is captured is not known.

Information collected by these methods indicates that tunas occur in the relatively upper layer of the ocean, and that their vertical distribution varies according to the species, with skipjack, bluefin, yellowfin, bigeye, and albacore living in deeper water in this order. The depth inhabited by fish of the same species may vary with area, sea or biological conditions.

We may summarize the available information for each species as follows:

(a) Bluefin (Thunnus orientalis)

In the coastal waters north and east of Japan their distribution is limited to the top 60 m (Kishinouye 1923). In the southern waters off Japan, bluefin occur within 150 m of the surface (Uda 1935; Nakamura 1949)

(b) Yellowfin (Neothunnus macropterus)

Known to occur to 160 m depth (Murphy and Shomura 1953, 1955; Nakagome 1958, 1961). Iversen and Yoshida (1957) stated that the trolling and live bait fishing catches of yellowfin tuna are composed of smaller size fish than those taken on longline gear, and consequently it is suggested that the smaller size fish have the tendency to inhabit shallower water layer than the larger ones.

(c) Bigeye (Parathunnus sibi)

In the North Pacific, the longline catch sharply increases below 100 m (Yoshihara 1952). In equatorial waters the catch also increases with depth (Murphy and Shomura 1955; Nakagome 1958; Watanabe 1958).

(d) Albacore (Germo alalunga)

Since albacore are taken by pole and line and troll fisheries, it is apparent that they come to the surface. Yoshihara (1952) stated that the longline catch in the North Pacific showed them most abundant between 130 and 170 m depth while Shomura and Otsu (1956) observed rather uniform distribution within the reach of the gear. In the equatorial waters it was observed that hooks in deeper water caught more fish (Shomura and Murphy 1955). In waters close to the Polar Front, albacore appear to migrate close to the surface, since small albacore of 50 to 60 cm in length are occasionally caught by salmon gill nets (Graham 1957).

(e) Skipjack (Katsuwonus pelamis)

The distribution of skipjack seems to be limited to the top 100 m since they are caught by pole and line, purse seine, trolling, longline, etc. This is further evidenced by the fact that they are frequently found in the stomachs of spearfishes. Accordingly it is concluded that they stay closer to the surface than other tunas (Kimura 1952; Watanabe 1958).

Recent development of the echo-sounder has made it possible to locate fish and fishing gears in the water. It was found by use of this instrument that actual depths of longline hooks were 15 to 60 m shallower than the estimated ones (Murphy and Shomura 1955). The images of schooling tuna (Kimura 1952) and individual tuna (Nishimura 1961; Maniwa 1961) were observed on the instrument, forming the basis for estimates of their vertical distribution and schooling habits (Fig. 19). Without doubt the echo-sounder will play a vital role in future developments in these fields though difficulties in identifying the species from their images are yet to be overcome.

3.2 Juveniles

As stated in sections 1 and 2, juvenile tunas 10 to 20 cm in length, are often found in the stomachs of adult tunas and spearfishes. This indicates that the vertical distribution of the young tunas coincides, at least partly, with that of the adults. There is some information, however, indicating that the young prefer somewhat shallower depths than the adults. Kishinouye (1926) reported the catch of juvenile skipjack, 10 to 14 cm in length, on the surface in water south of Kyushu. Watanabe (1958) observed in the equatorial waters in the western Pacific that the young of tunas were frequently found in the stomachs of spearfishes. Since spearfishes feed in shallower water than the adult tuna, this also supports the above assumption.

3.3 Larvae

There are few observations on the vertical distribution of tuna larvae.

Wade (1951)noted marked differences in larval abundance between day and night surface catches, and suggested that tuna larvae make a diurnal vertical migration.

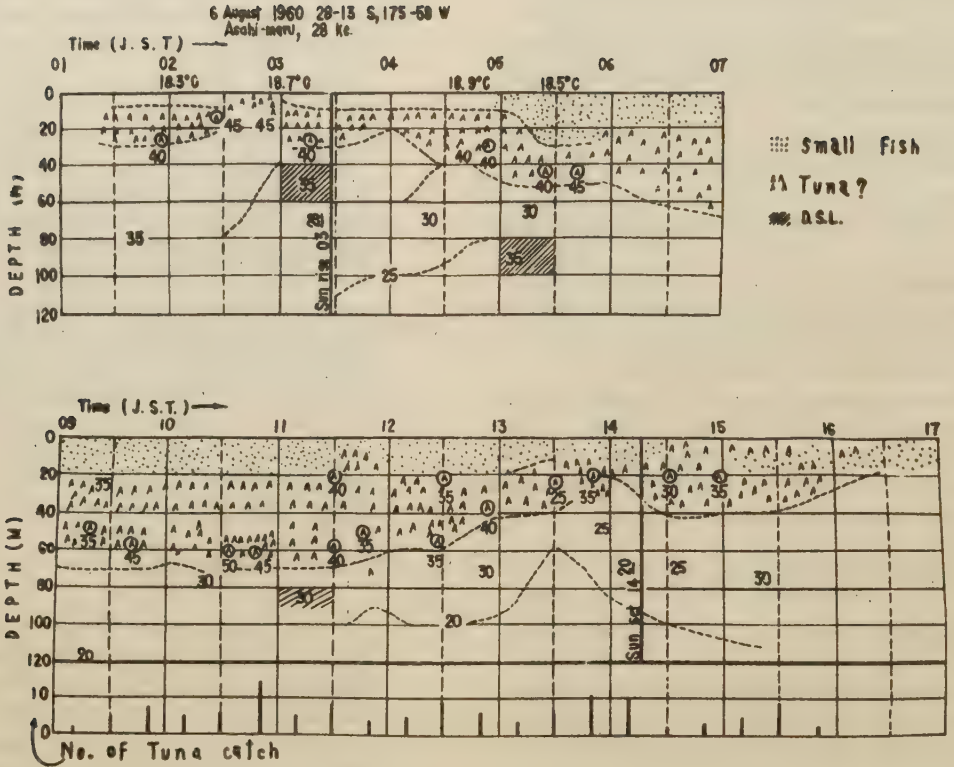

Fig. 19 Showing the diurnal vertical movement of fish school (possibly tuna) based on the images recorded by the echo-sounder (from Nishimura 1961).

Matsumoto (1958) and Strasburgh (1960) made collections down to 200 m depth by means of horizontal open-net tows (surface), and oblique open-net tows (0 - ca. 60 m 70 - 130 m and 140 - 200 m), and noted that the larvae were most abundant within about 60 m of the surface. Below that layer their abundance decreased with increased depth; 20 to 25 percent of the catch were obtained at 70 to 130 m and between 140 and 200 m it decreased to almost nothing. Diurnal vertical movement of the larvae was recognised from the fact that the change in the catch between day and night was greatest at the surface and became smaller at depth (Fig. 20, 21). The diurnal change did not vary noticeably with size of the larva.

Yabe and Ueyanagi (1961) made simultaneous horizontal tows by means of open-nets at three different depths: surface at about 20 m, at 40 to 50m and obtained similar results. The greatest disparity in the occurrence of tuna larvae between day and night was observed on the surface and the diurnal vertical movement was evident within the top 50 m. Istiophorid larvae, collected at the same time, showed movement in the reverse direction (Fig. 22).

4 EFFECTS OF ENVIRONMENTAL FACTORS

4.1 Adults

There are a number of reports dealing with the effects of environment, both biotic and abiotic, upon the distribution of tunas, as outlined below:

(a) Water temperature

Though the temperature range where tunas are found is fairly wide, their main concentrations occur within a narrow range specific to each species. For albacore in the northeast Pacific, concentration occurs only between 57° and 65°F (14° to 18°C) (Shomura and Otsu 1956; Alverson 1961) (Fig. 23). In the northwest Pacific, the range lies between 17° and 22.8°C (63° to 73°F), although albacore are found in waters between 14° and 25°C (57° to 77°F) (Uda 1935; Kawasaki 1957 a, b).

Skipjack, on the other hand, appear in large concentration in waters between 20° and 23° C (68° - 73°F) (Uda and Tukusi 1934; Blackburn 1961). In the northwest Pacific bluefin are found in waters between 13° and 18°C (55° - 64°F) (Uda 1935).

Besides these factual observations, there is a comprehensive analysis by Suda and Shiohama (1962) on the relation between water temperature and the distribution of albacore in the northwest Pacific. They stated that the temperature preferred by albacore varied by season, area, size of fish, etc.

A shallow thermocline may act as a physical barrier limiting the vertical migration of albacore, with gillnets and purse-seines being most successful under such a condition (Alverson 1961).

Schaefer (1961), Blackburn (1961), and others observed the distribution of tunas being affected by the annual variation of water temperature in the eastern Pacific. Johnson (1961) also noted that the year-to-year variation of the catch of albacore along the Pacific coast of the United States corresponds closely with the variation in water temperature and suggested that the potential availability of albacore could be predicted from a consideration of the temperature anomaly during May and June prior to fishing season (Fig. 24). Seckel and Austin (1961) reported that the annual catch of skipjack in the Hawaiian waters were very closely related to the time of the late winter reversal from cooling to warming of the surface waters in the area of the fishery (Fig. 25). Uda (1961a) recognised that skipjack, albacore, and bluefin tuna in the western and eastern Pacific show certain variations in abundance and availability which may be temperature controlled.

In summary, temperature may be excluded as a direct factor influencing the distribution of tunas as far as the subtropical and tropical areas are concerned, but in the fringe of their distribution, or more generally, in the temperate zone, it can be a limiting factor and hence, in many instances, is an important indicator of their distribution.

(b) Salinity

Around Japan, good albacore fishing grounds are known to be found in waters with salinity between 19.1 and 19.3 o/oo (Kawasaki 1957 a, b, 1960). No such relation was

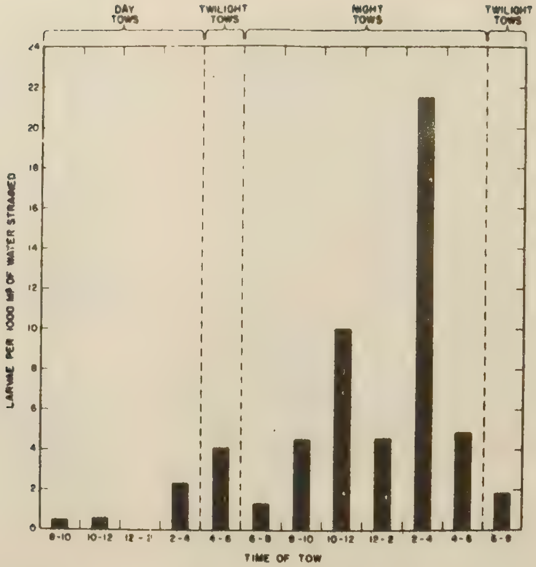

Fig. 20 Larval-tuna catch at various times of the day (from Matsumoto 1958).

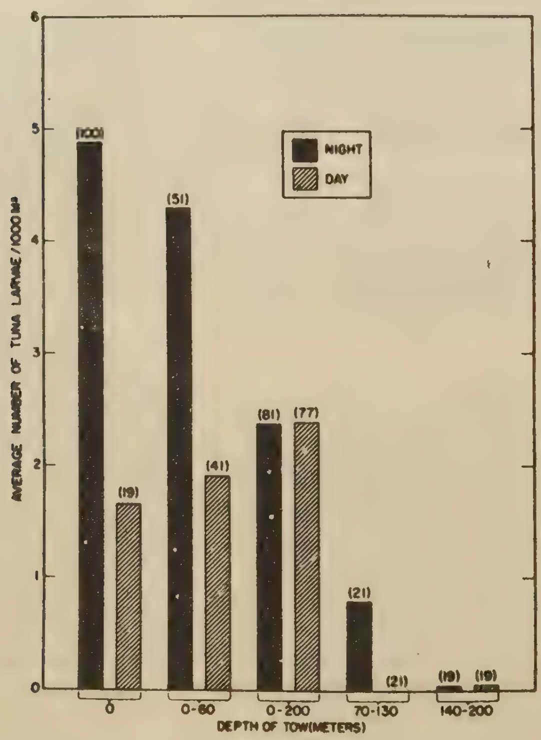

Fig. 21 Night and day variation in larval tuna catch with depth. Number of tows is shown in parentheses. The number of larvae obtained at each depth were: 0 m-927; 0 to 60 m-432; 0 to 200 m-592; 70 to 130 m-20; and 140 to 200 m (from Strasburg 1960).

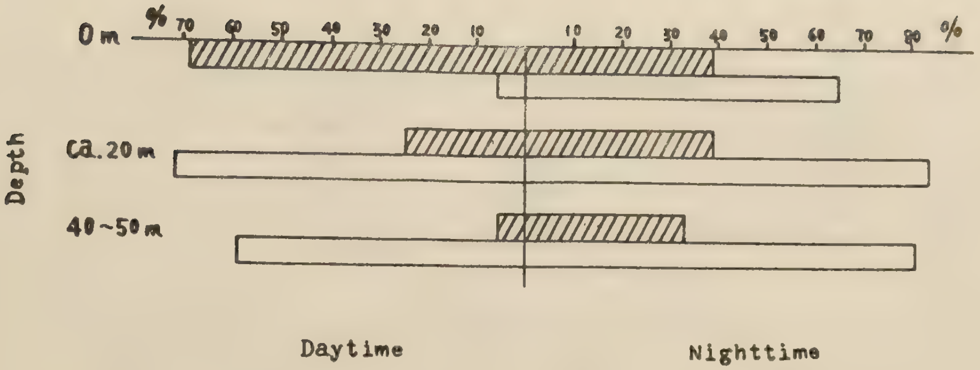

Fig. 22 Vertical distribution of larvae showing:
(a) % number of tows from which larvae were captured
(b) depth distribution with time
White - tuna larvae; Hatched - istiophorid larvae
(from Yabe and Ueyanagi 1961)

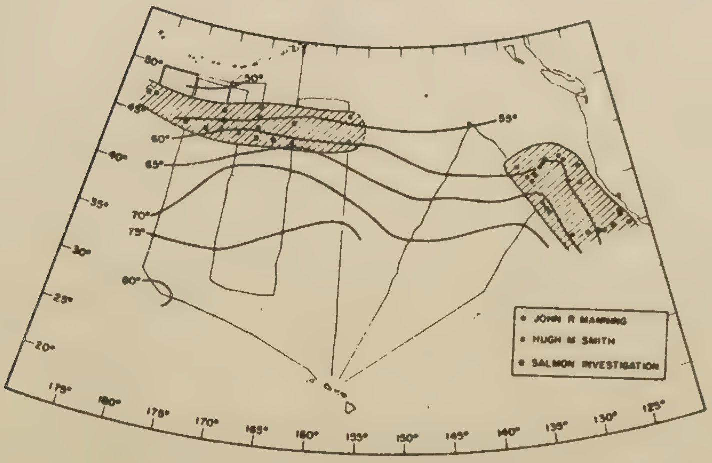
JOHN R MANNING
HUGH M SMITH
SALMON INVESTIGATION
175°
180°
175°
170°
165°
160°
155°
150°
145°
140°
135°
130°
125°
20°
25°
30°
35°
40°
45°

Fig. 23 Location of albacore taken in the North Pacific by exploratory vessels, July to September 1955 (from McGary, Graham and Otsu 1961)

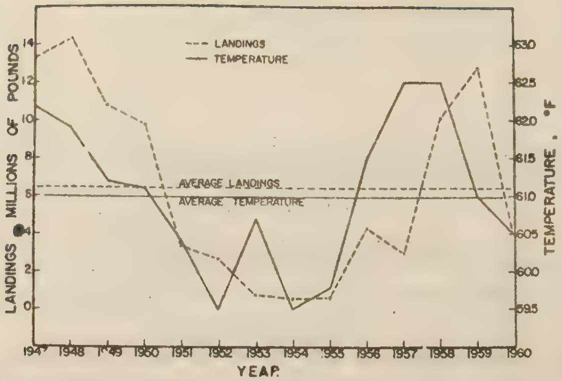

Fig. 24 Average sea temperatures for August for the oceanic area bounded by 40°N to 50°N latitude and from the west coast of North America to 130°W longitude for the years 1947 to 1960, and total landings of albacore in Oregon and Washington for the same years (from Johnson 1961)

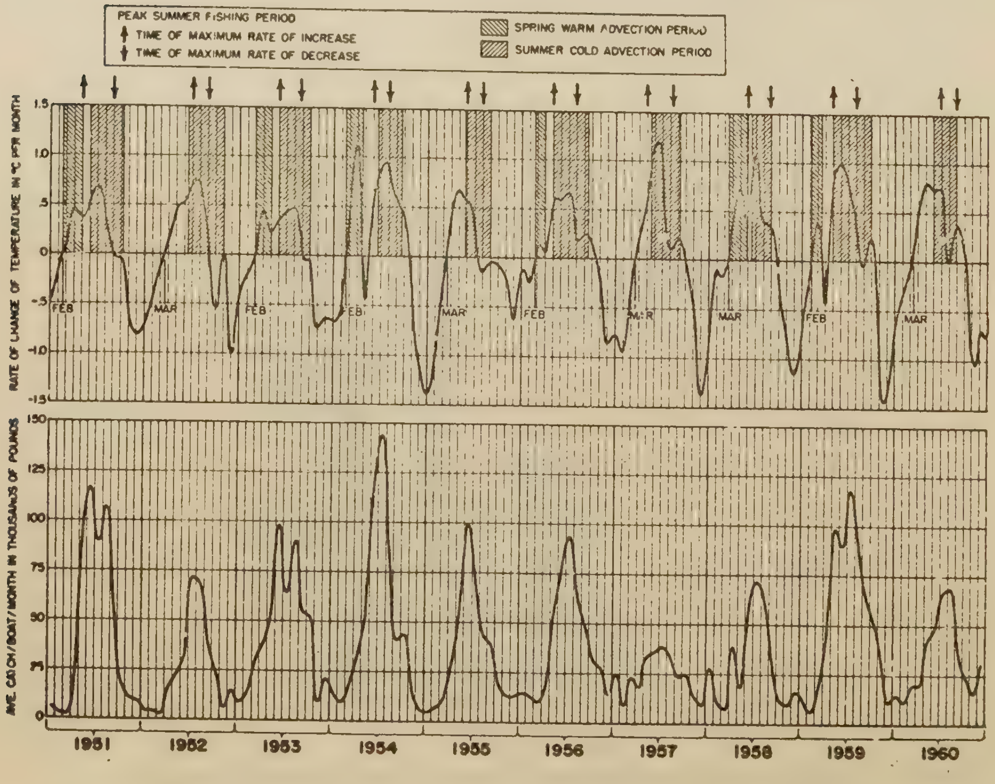

Fig. 25 Upper panel: Heating curve, surface waters, Koko Head, Oahu.
Lower panel: Hawaiian skipjack landings, monthly catch per unit of effort, 1951 to 1960 (from Seckel and Austin 1961).

recognised in bigeye and yellowfin around the Caroline Islands (Nakagome 1958).

(c) Transparency

In the northwest Pacific, Alverson (1961) noted the presence of the so-called "tuna water", or dark-greenish warm water (>58°F) where albacore were most abundant. Murphy (1959) found that the catch of albacore by gill-nets was largely dependent upon, and varied inversely with, the transparency of water on the fishing grounds; the catch by trolling, on the other hand, was better in more transparent water. It is reported that the transparency (visibility) in good skipjack fishing grounds around Japan ranges between 15 and 20 m, while that of yellowfin in the Sulu Sea is 26 and 31 m.

(d) Current system, water type

Some information is available on the distribution of tunas in relation to current systems or water types with varying physical and chemical characteristics. As mentioned in 1.1 the longline fishing ground of each tuna species is formed in a band-like shape extending from east to west. Nakamura (1954), noticing the fact that the boundaries of tuna distribution coincided with those of current system, studied the relation between their distribution and the current system in the Pacific. He found that the center of distribution occurs in different current systems depending on the species, and that within the same species, the center of distribution of the fish in different growth stages occurs also in different current systems. Thus, he hypothesized that each current system presents a specific biosphere to each species of tuna.

In an examination of this hypothesis, Nakamura and Yamanaka (1959) and Yamanaka and Anraku (1961) found a close relationship between distribution of tunas and the current system or water type in the Indo-Pacific region and pointed out the possibility that the distribution or migration of tunas will become a good indicator of oceanographic structure and conditions (Fig. 26).

Brown and Sherman (1961) found a close relationship between the characteristics of various water types in Hawaiian waters, with principal emphasis on temperature and salinity, and seasonal movement of these.

(e) Productivity

Uda (1961b) studied the relation of oceanic fronts to tuna concentration, and reported that in the western Pacific tuna are to be found along fronts, located in cool or warm eddies, and in zones of upwelling. Such eddies were associated with the Polar Front, the Subtropical Convergence, and were found near the Equator.

In the eastern Pacific, Brandhorst (1958) and Blackburn (1961) examined various oceanographic conditions in the light of the distribution of tunas and concluded that the distribution of tunas and productivity of the area are benefited by such factors as the formation of shallow thermoclines, domes, eddies, and wakes caused by the presence of islands. McGary and Stroup (1956), Shomura and Otsu (1956), McGary, Graham and Otsu (1961), defined the area of largest concentration of albacore in the North Pacific as being closely associated with the highly productive "transition zone" (Fig. 27). Cromwell (1953), Sette (1955), Murphy and Shomura (1953, 1955) reported that the upwelling and divergence zones in the mid-Pacific equatorial waters, which are formed under the influence of the trade wind, produce very favorable conditions for increased productivity and consequently affect the abundance of yellowfin tuna (Fig. 28). King and Hida (1957) also reported that in general there was a high degree of covariation in yellowfin and zooplankton abundance in respect to the current system in the central equatorial Pacific (Fig. 29).

Recently a new approach is being made to examine the abundance of tunas in terms of forage organisms which are of higher trophic level than zooplankton (King and Iversen 1961). Between the abundance of zooplankton and forage organisms, a parallel relationship is noticeable, as is shown in Fig. 30 and further, the latitudinal variation of the overall abundance of tunas agrees in a general way with that of zooplankton and forage organisms. The abundance of tunas as well as zooplankton and forage organisms is generally high north of approximately 30°N and south of 15°N with the intermediate zone of low abundance. Thus,

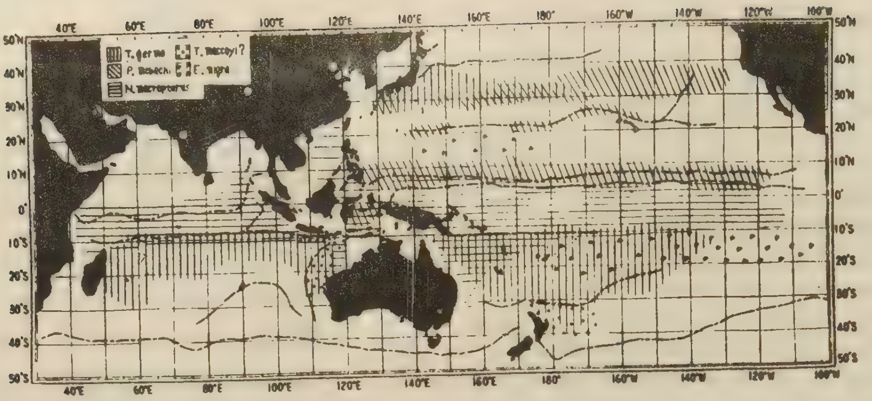
T. germo
T. maccoyi?
E. nigra
N. macropterus
40°E
60°E
80°E
100°E
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
30°S
40°S
50°S

Fig. 26 Diagramatic distribution of the fishing ground of tunas and marlins and the boundary of the ocean current (October to March) (from Nakamura and Yamanaka 1959).

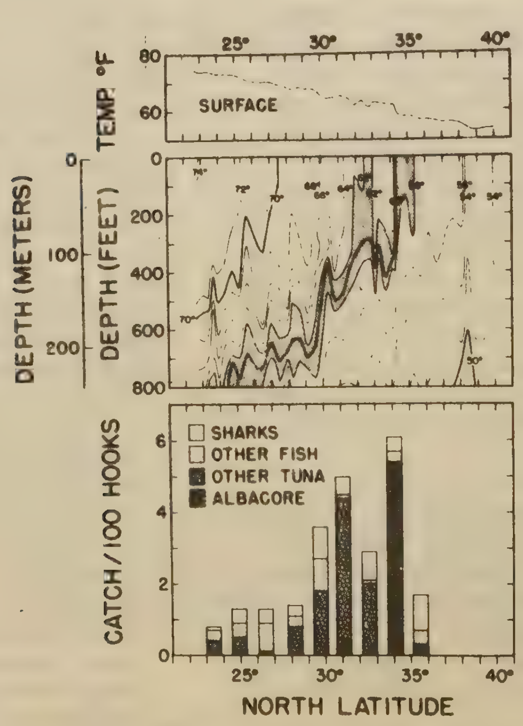

Fig. 27 Vertical temperature profile, Hugh M. Smith cruise 25 January 1954 and longline catch/100 hooks, John R. Manning cruise 19 January 1954, along 160°W longitude (from McGary, Graham and Otsu 1961).

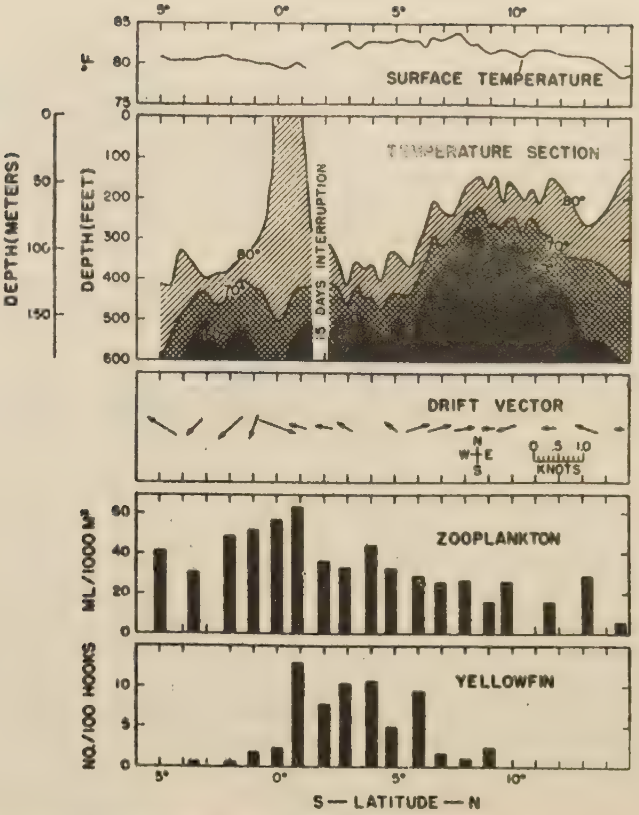

Fig. 28 Surface temperature, vertical temperature field, longline drift, zooplankton abundance in the upper 200 m, and the yellowfin tuna catch along long. 150°W 22 August to 25 September 1951 (from Sette 1955)

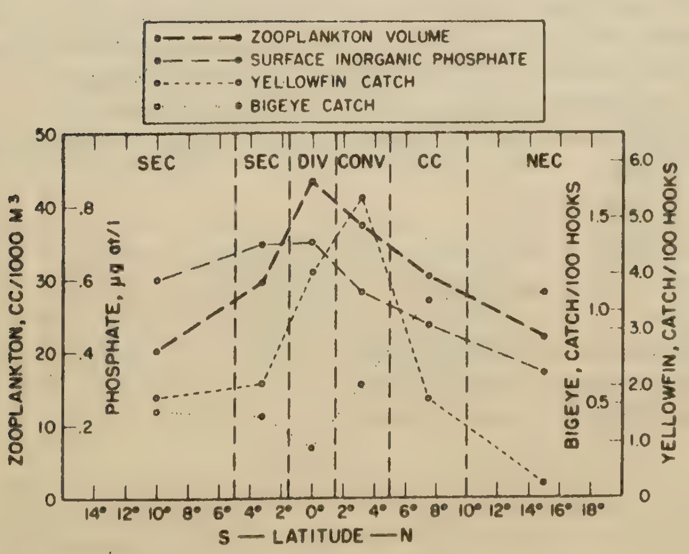

Fig. 29 Variation with the current system in yellowfin and bigeye catch on longline gear, zooplankton volumes (adjusted) and surface inorganic phosphate, for the range of longitude 120°W to 180° (from King and Hida 1957)

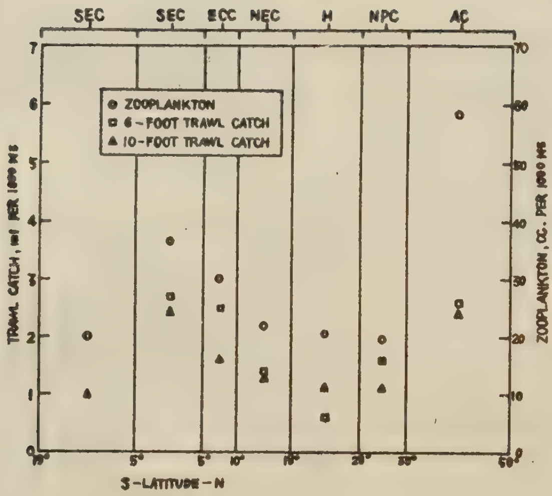

Fig. 30 Variation with latitude in the average volume of trawl catch per cubic meter of water strained by the 6- and 10-foot Isaacs-Kidd trawls, as compared with the zooplankton catch. The zooplankton data south of 30°N latitude are from King and Hida (1957 a, b); those to the north of 30°N are from the files of the U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu
(from King and Iversen 1961)

AC - Aleutian Current Area
NPC - North Pacific Current Area
H - Hawaii Area
NEC - North Equatorial Current Area
ECC - Equatorial Counter Current Area
SEC - South Equatorial Current Area

it is logical, from the macroscopic view point, that the overall abundance of tunas is associated with the productivity of the water. However, our present knowledge is not sufficient for us to establish a general rule between the productivity and the abundance of each species [1] or that of their longitudinal variation within each current system.

4.2 Larvae

Information is only sparsely available regard- the effect of environment on the distribution of tuna larvae.

Matsumoto (1959) reported the maximum and minimum surface temperature of the water, where larvae of frigate mackerel and little tunas were collected, to be 29° and 22.5°C for the former and 29.0° and 23.5°C for the latter. Strasburg (1960) presumed the fringe of the distribution of tunas to be defined approximately by the 60°F (or about 15.6°C) isotherm, on the basis of his observation on their vertical distribution (Fig. 31). As indicated above, larvae of tunas tolerate a fairly wide range of temperature, but it is estimated that their largest concentration occurs only in waters exceeding approximately 24°C, both horizontally and vertically.

The distribution of tuna larvae is confined within the tropical and subtropical waters, whose approximate boundary is demarcated by the Subtropical Convergence, or where the North Equatorial, Equatorial Counter, and South Equatorial Currents dominate. Larvae are not found at higher latitudes than the Subtropical Convergence (see 1.3).

Most larvae are found above the thermocline. Though the factors limiting the vertical distribution of tuna larvae are not yet known, high mortality due to low temperatures or lack of oxygen is suspected to be the cause of the almost total absence of larvae below the thermocline.

As stated in the previous section, an apparent relationship is recognized between the abundance of adult tunas and the productivity of the water, indicated by the availability of zooplankton. (The productivity is highest between 5°S and 5°N, intermediate in the Equatorial Counter Current area, and lowest both in the North Equatorial Current area, north of 10°N, and in the South Equatorial Current area, south of 5°S (King and Hida 1957; King and Iversen 1961). However, no direct relation is likely to exist between the abundance of larvae or juveniles and productivity.

The reasons are as follows:

(a) Albacore juveniles are abundant in the waters of low productivity. [2]

(b) Although juveniles of bigeye and yellowfin (Yabe et al 1958) and larvae of skipjack and yellowfin (Matsumoto 1959), are found abundant in the area of high productivity, it seems more reasonable to assume this coincidence as indication of the dependence of the juveniles and larvae on the adults.

There are other noteworthy findings in respect to vertical movement and natural mass mortality. Strasburg (1960) noted almost complete disappearance of tuna larvae from the surface at sunset while studying their diurnal movement. He explained this temporary phenomenon as being related to the rise of the deep scattering layer towards evening and the resultant increase of invertebrate plankton in the surface layer (Fig. 32). He presumed that the inverse relationship in the behavior of tuna larvae and invertebrate plankton was due to differences in their reaction to light intensity, and further inferred that tuna larvae are not likely to be a constituent of the deep scattering layer.

Strasburg (1959) also reported an incidence of natural mass mortality of frigate mackerel in Hawaiian waters. His explanation is quoted as follows: "The definitive cause of death could

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[1] For example, although a close relationship between the abundance of yellowfin and zooplankton is recognised in the equatorial waters of the central Pacific, the situation for bigeye is quite different. They are abundant in the Equatorial Counter Current and North Equatorial Current areas where zooplankton are less abundant (King and Hida 1957).

[2] Identification of albacore larvae is not possible, but they are presumed to be distributed in the same area as the juveniles.

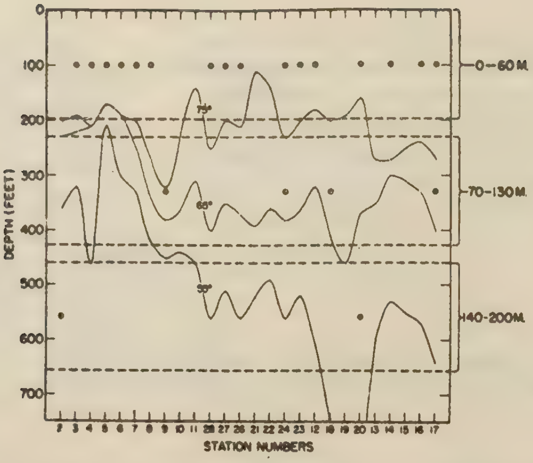

Fig. 31 Isotherm depths at plankton stations. Stations are ranked from north to south; temperature and depth measurements derived from bathythermograph traces. Dots represent closing net tows yielding tuna larvae (from Strasburg 1960)

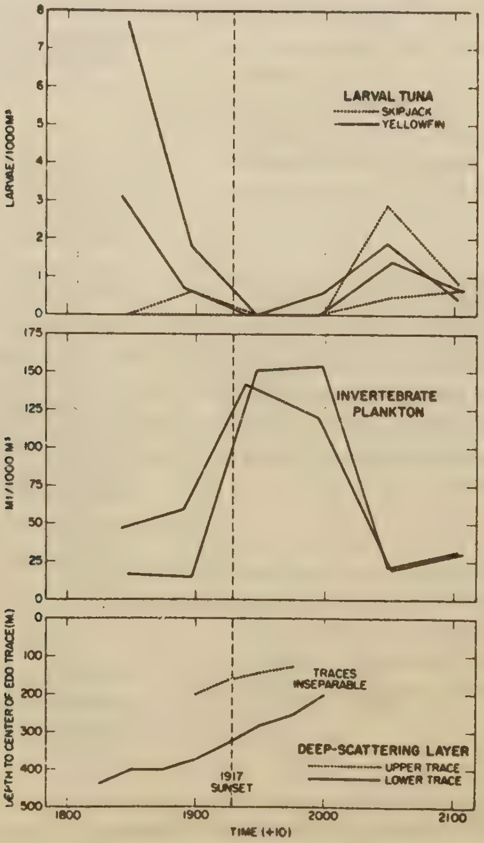

Fig. 32 Effect of sunset on larval tuna and invertebrate plankton catches, and depth of deep-scattering layer. Plotted time for larval tuna and plankton catches is midpoint of towing interval (from Strasburg 1960).

not be determined. There were no signs of predation, disease, or parasitism, but starvation could not be definitely excluded as a factor. It was tentatively hypothesized that the mass death was brought about by passage through an area having marked discontinuities in its surface water temperature". Such a mass mortality might have a grave effect upon the distribution and abundance of tuna larvae, but the actual damage cannot be measured at present stage of our knowledge.

5 DISCUSSION

The fact that the distribution of tunas extends over the tropical, subtropical, and temperate zones indicates that the mechanism of their distribution cannot be explained by one or two specific environmental factors, such as water temperature, salinity or productivity. In fact, the relation of tunas to environment has been shown to be quite variable (by species, areas, and even growth stages within a single species), as outlined in section 3.

In concluding the review of past observations on the effect of environment, we should like to point out some of the outstanding problems and make a few suggestions in respect to them.

(a) In the temperate zone of the North Pacific, water temperature has been recognised as a vital factor affecting the distribution of tunas, and upon which considerable knowledge has been accumulted. To elaborate further upon this relation, reliable means must be developed to predict the conditions favorable to the tuna fisheries. However, since water temperature is not critical in tropical and subtropical waters, it is necessary to seek other factors which are indicative of the water types tunas prefer.

Use of oceanographic monitoring stations (Austin and Barkley 1961) will contribute a great deal toward predicting variations in distribution and abundance of tunas in terms of variations in environmental factors, such as water temperature, salinity, etc.

(b) The aggregation of tunas has been explained in terms of the oceanic front, "shiome", and "transition zone", in the North Pacific and the high productivity resultant from upwelling in the equatorial waters. These findings are very important contributions to our knowledge, but it should be pointed out that the past analyses have placed too much importance on the feeding requirements of tunas. There are some instances where the distribution of tunas cannot always be explained by productivity. For example, the abundance of yellowfin in the equatorial waters seems to be expounded by productivity, but apparently this logic does not apply in the case of bigeye (see 3.1(c) & footnote 2). Accordingly, it is necessary to consider the effects of environment in terms of spawning and other requirements as well as feeding.

(c) In the above mentioned investigations, the effects of environmental factors upon the distribution of tunas have been analysed for the purpose of finding new or better fishing grounds, and these investigations have aimed at explaining the cause-and-effect relationship between distribution and environmental factors.

There has been another line of investigation to collect factual information on the distribution of tunas in terms of current systems, based upon the hypothesis that each current system presents a specific biosphere to each species of tuna (see 4.1(d)).

It is advisable to combine these two lines of approach with the following logical sequences:

Firstly, to clarify the characteristics, specific (B) and common (A) to all species of tunas;

(A) As to the common characteristics, there are the following phenomena; The early life from eggs to juveniles occurs only in the tropical and subtropical waters. Although the present knowledge is not sufficient to identify precisely the factors affecting the distribution of early life stage of tunas, water temperature most likely plays a vital rôle. Productivity does not seem to be a very influential factor.

In the later life, where growth of fish is rapid, tunas have very wide distribution from tropical to temperate zone, and their abundance is high both in the equatorial and temperate zones with an intermediate zone of low abundance. In this case, productivity is likely to be very important.

(B) With the above common features, the distribution of tunas is very specific. Little tunas, frigate mackerel, and bonito spend all their lives close to land masses, while albacore, bigeye, yellowfin and skipjack live far from the shore. The latter group is further broken down into the following three sub-groups:

(a) The group of fish which spend their early life from eggs to juveniles in the tropical and subtropical waters and their subsequent life in the temperate waters, bluefin and albacore.

(b) The group of fish which spend their early life in tropical and subtropical waters and migrate during their later life between the above and temperate waters, bigeye and skipjack.

(c) The group whose entire life is mostly confined to tropical and subtropical waters, yellowfin.

Since the distribution patterns of tunas are the result of their adaptation to the environment during the long process of evolution, it is extremely difficult to relate the distribution patterns of tunas to environmental factors. It is suggested, however, that this question should be examined with the following points in mind:

(i) In view of the fact that the past research has placed stress almost exclusively upon the feeding requirements, it is necessary to consider the distribution patterns of tunas in terms of their reproduction and other physiological requirements.

(ii) Since the physiological requirements differ in the different stages of growth, the analysis should take this into consideration.

(iii) As stated in sections 1 and 2, a good deal of information has been collected regarding the vertical and horizontal distribution, but it is still necessary to accumulate more factual knowledge.

Adults

Available information has been collected only through fisheries. So, where no fishing activity is in progress, there is very little, if any, information and even where it is available, the quality is not uniform for different species, areas, and seasons, since it depends entirely upon the degree of exploitation, kind of gear employed, and so on.

Regarding the horizontal distribution, general knowledge has been available to the fringe of their distribution in the northern hemisphere, but only little is known for the southern hemisphere. Particularly, no information is available south of 40°S throughout the world. Thus, it is recommended that investigations on these unknown factors be initiated. Tagging is considered to be an effective method of unveiling the geographical distribution in terms of species or population identification of tunas.

Our knowledge of the vertical distribution is also extremely unsufficient; however, it is expected that this situation will be improved through the use of various electronic instruments, such as echo-sounders, sonars, underwater televisions, etc. Recent development of these electronic instruments is remarkable. Introduction of this modern equipment will contribute greatly to enhancing our knowledge not only of qualitative but also of quantitative aspects of the distribution of tunas.

Larvae and Juveniles

Information regarding the early life of tunas before they become vulnerable to fisheries is much more scanty than that of their later life. The following difficulties must be overcome as pre-requisites to defining the distribution of eggs, larvae, or juveniles as well as determining the effects of the environment on these stages:

(a) Specific identification

Criteria for specific identification of larvae and juveniles, to say nothing of eggs, have not yet been established. (A tentative key to the postlarvae of tunas and related species is given later).

For the specific identification of larvae and juveniles, we advise the examination of their internal characters by means of X-ray (Watson and Mather III 1961) or other appropriate technique, and combine with information with observations on their external characters. For eggs and newly hatched larvae, artificial fertilization and subsequent rearing of larvae are recognized as a necessity.

(b) Collection of juveniles

It is urged that the efficiency of methods for collecting free-swimming juveniles be improved. There are at present three major methods for collection: examination of stomach contents of adults, midwater-trawling, and night-light collecting. All of these are unfortunately far from satisfactory for quantitative evaluations. The method of stomach content analysis has an advantage in that samples are available through the commercial fisheries. However, this kind of information is of indirect quality. Midwater-trawl collecting requires substantial improvements in the operational techniques as well as the gear employed (King and Iversen 1961). A third method, or night-light collecting, was reviewed at the Pacific Tuna Biology Conference in Honolulu, August 1961, and the Conference recommended that this method be employed on a world-wide basis.

(c) Evaluation of larval abundance

It is advised that the method be standardized to make the results of investigations representative of the actual abundance. Strasburg (1960) considered that plankton net trawling is the best available method to evaluate the abundance of tuna larvae and that depths from the surface down to 200 m, the entire depth range of larval tuna, should be covered.

As a pre-requisite to initiate a world-wide survey, it is recommended that methods of plankton-net trawling be standardized. Time and space intervals for sampling should be carefully designated, because it is presumed that the distribution of larvae is not at random (Strasburg 1960).

(d) Needs of joint research program

To perform an analysis of the population dynamics of tunas on the basis of the mortality during their early life stages, it is necessary to collect quantitative information on the survival of young from eggs to juveniles, in terms of both space and time. This kind of research requires coverage of the entire area of their distribution, besides the solution of the many technical problems stated above.

In order to realize this objective, it is desirable to initiate a joint research program on an international basis, involving as many vessels as practicable.

6 ACKNOWLEDGEMENTS

The authors wish to acknowledge the co-operation given by the staff of Nankai Regional Fisheries Research Laboratory. Thanks are also due to Mr. K. Yonezawa for his assistance in preparing the English manuscript.

7 APPENDIX

Key to the postlarvae, ranging from approximately 4 to 8 mm in total length, of eight species of tunas and related fishes from the Indo-Pacific region.[1]

a_1 Chromatophores present on the trunk.

- b_1 Presence of chromatophores over the forebrain.
  - c_1 Presence of a distinct chromatophore on the ventral midline of the caudal region. No chromatophore at the symphysis of the pectoral girdle. ....Katsuwonus pelamis
  - c_2 A series of chromatophores along the midventral line of the trunk, from the vicinity of the anal fin base to the caudal region. Chromatophore present at the symphysis of the pectoral girdle. ..... Euthynnus yaito
- b_2 No chromatophores over the forebrain.
  - d_1 Three short series of closely set chromatophores on the middorsal, midlateral, and midventral lines of the caudal region. Presence of a chromatophore at the symphysis of the pectoral girdle. ..... Auxis thazard
  - d_2 1 to 3 chromatophores along the dorsal margin of the trunk and 1 to 5 chromatophores along the ventral margin of the trunk.
    - e_1 Initial dorsal chromatophore being posterior to the origin of the second dorsal fin. ..... Thunnus orientalis

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[1] This key is a tentative one, because the positive identity of all the species is not yet established. For the preparation of this key, the following papers were used: Matsumoto (1958), Mead (1951), Yabe and Ueyanagi (1961).

e_2 Initial dorsal chromatophore being anterior to the origin of the second dorsal fin. ..... Kishinoella tonggol

d_3 1 to 5 chromatophores along the ventral margin of the trunk and no pigmentation along the dorsal edge of it. ...... Parathunnus sibi

a_2 Complete lack of chromatophores on the trunk.

f_1 Presence of chromatophores at the tip of the lower jaw. ..... Neothunnus macropterus

f_2 No chromatophores at the tip of the lower jaw ..... Germo alalunga

Methodological Paper No. 2

SUBPOPULATION IDENTIFICATION

By

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Abstract

The methodology of subpopulation identification includes morphometric studies, tagging experiments, blood group studies, and miscellaneous other studies. The methodology of each is reviewed. Blood group studies are particularly attractive, since they permit the study of characteristics under genetic control.

Although some advances have been made in morphometric studies, results obtained are frequently equivocal. Important results have been obtained from tagging experiments on albacore in the North Pacific, yellowfin and oceanic skipjack in the eastern Pacific, and oceanic skipjack in the central Pacific. Blood group studies have only recently commenced, but interesting results have been obtained for albacore in the Pacific and Indian Oceans, and for oceanic skipjack and bigeye in the central Pacific.

The major tasks of identifying tuna subpopulations remain. It is to be hoped that basic problems will not be lost sight of in the pressure of solution of pressing practical problems.

IDENTIFICATION DES SOUS-POPULATIONS

Résumé

Les méthodes d'identification des sous-populations comprennent des études morphométriques, des expériences de marquage, des études de groupes sanguins et diverses autres analyses annexes. L'article passe en revue la méthodologie de ces différents types d'études. Les études des groupes sanguins présentent un attrait particulier, car elles permettent d'examiner les caractéristiques soumises à l'influence de la génétique.

Bien que les études morphométriques aient fait quelques progrès, les résultats obtenus sont encore souvent incertains. Des résultats importants ont été obtenus avec des essais de marquage effectués sur le thon germon du Pacifique Nord, sur le thon à

nageoires jaunes du Pacifique oriental et sur la bonite océanique à ventre rayé du Pacifique oriental et central. Les études des groupes sanguins sont encore très récentes, mais des résultats intéressants ont été déjà réunis sur le thon germon des océans Pacifique et Indien, sur la bonite océanique à ventre rayé et sur le thon obèse du Pacifique central.

Les travaux les plus importants sur l'identification des sous-populations de thons restent encore à faire. On souhaite que les problèmes fondamentaux ne soient pas négligés sous la pression des problèmes pratiques à résoudre.

IDENTIFICACION DE SUBPOBLACIONES

Extracto

La metodología de identificación de subpoblaciones incluye estudios morfométricos, de grupos de sangre y varios otros, y experimentos de mercado. Se reseña la metodología de cada uno. Los reconocimientos de los grupos de sangre son de especial interés porque permiten estudiar las características bajo control genético.

Aunque se han hecho algunos adelantos en los estudios morfométricos, los resultados obtenidos son con frecuencia equívocos. Se han logrado importantes resultados en los experimentos de marcado de albacora en el norte, de atún de aleta amarilla y barrilete en el este, y de barrilete en el centro del Pacífico. Los estudios de grupos de sangre sólo se han iniciado recientemente, pero se han obtenido resultados interesantes para la albacora en los océanos Pacífico e Indico y para el barrilete y patudo en el Pacífico central.

Quedan por dilucidarse las principales cuestiones relacionadas con la identificación de subpoblaciones de atún y es de esperar que no se pierdan de vista los problemas fundamentales, por tener que encontrar solución urgentemente a los problemas prácticos.

1 INTRODUCTION

Even as the tunas are cosmopolitan creatures, so are the tuna fisheries cosmopolitan in nature. The products of these fisheries compete in a world market. Furthermore, the yield of the world tuna fisheries has about doubled in the last decade and it has been estimated (Chapman, in press) that it will double again in the next decade or decade and a half.

The nature of the fisheries and the trend of increasing world yield contribute a large element of urgency to the problem of subpopulation identification. Subpopulation identification involves the recognition and definition of self-sustaining population units. The author prefers the term "subpopulation" for such natural units, but also uses the terms "population unit" and "interbreeding population" as exact synonyms.

The importance of subpopulation identification has been recognized for more than half a century and has been reviewed extensively in recent years. There seems to be little point in plowing the same field at length here. Rather, it is sufficient (1) to emphasize that subpopulations are interbreeding groups with genetic continuity within units and genetic discontinuity between units and (2) to provide references to the recent reviews of the problem (Marr, 1957, in press; Marr and Sprague, in press; Mužinić, in press; Mužinić and Marr, in press).

2 METHODOLOGY

Of the methods available for the study of subpopulations, two classical methods have been widely applied to the tunas, with the recent addition of a third method borrowed from other disciplines. The classical methods are the study of body proportions, or morphometrics, and tagging experiments. The newer method is that of studying blood group systems by immunological techniques.

2.1 Morphometrics

The study of morphometrics involves the comparison of one or, usually, several body proportions among two or more samples. Originally such comparisons were made on the basis of ratios, i.e., head length/body length (Heldt, 1931). Subsequently, comparison of ratios was generally abandoned in favor of regression analysis of original variates, thereby avoiding difficulties introduced by allometric growth and intercepts not passing through the origin (Marr, 1955).

Among the tuna morphometric studies making use of regression analysis may be mentioned the works of Broadhead (1959), Frade (1931), Godsil (1948), Hennemuth (1959), Hiyama and Kurogane (1962), Postel (1956), Royce (1953), and Schaefer (1955). (No effort will be made to supply a complete list of references. Such are available in the annotated bibliographies of Corwin (1930), Shimada (1951), Van Campen (in press), and Van Campen and Hoven (1956).)

In general, these works involved individual comparisons, of the body proportions used, between pairs of samples. For example, if data on 15 body dimensions were available in three samples from different localities, then body dimension 1 would be compared between areas A and B, between B and C, C and A, and so on for the other 14 dimensions, making a total of 45 comparisons. If a significant difference (at whatever probability level the investigator was willing to gamble) was found between particular samples, it was generally (but not universally) concluded that the samples had been drawn from distinct population units.

It is possible, especially in the case of large samples, to find significant differences even though the data show considerable overlap. Royce (1957, in press) greatly advanced the methodology of morphometric comparisons in two respects. First, he pointed out that significant differences in the presence of overlap do not indicate that the samples represent distinct units, but rather that they were not drawn from the identical unit. In fact, the amount of overlap is a measure of the amount of mixing that could occur. The amount that actually does occur would have to be determined by independent means, such as a tagging experiment. Second, he extended and modified existing methods so that it is possible to compare several dimensions simultaneously. This adds greatly to the power of the tool.

In spite of these advances, there remains one major source of uncertainty in interpreting results. It is known for several species of fishes that body form is modified by the environment (for example, by temperature during the early life history, by food supply, etc.) Although such environmental modification of body form has not been experimentally verified in the case of the tunas, there is no reason to believe that it does not obtain for these species as well. Thus, significant differences in tuna dimensions may be indicative of environmental differences, rather than of subpopulation differences.

2.2 Tagging experiments

Tagging experiments (and the related marking experiments) have been a tool of the fishery biologist for practically as long as there has been a field of fishery biology. It has only been within the past decade, however, that the technique has been applied to the tunas with any degree of success.

Perhaps the earliest successful tuna tagging experiments were those performed unintentionally. Sella (1929) and Heldt (1932) have reported on hooks recovered from bluefin tuna in the Mediterranean and eastern Atlantic. Because of the unique characteristics of hooks used in different fisheries, it was possible to infer movements on the basis of hook recoveries. Such recoveries were, of course, infrequent.

Early attempts to tag tunas employed tags attached around, or to, the caudal peduncle. The numbers of individuals tagged in these experiments were generally small. The earliest tuna tagging was probably that of Sella in 1911, who placed tags around the caudal peduncles of 10 bluefin tuna (Rounsefell and Kask, 1945). Similar tagging experiments include those of Frade and Dentinho (1935), on bluefin tuna, and of various Japanese workers, Fukuda and Iizuka (1940) for example, on oceanic skipjack. Recoveries from these tagging experiments were either zero or few in number and occurred over a short period of time. These results are not surprising in view of Sette's (1950) experimental results with tags around the caudal peduncles of Atlantic mackerel.

There followed a series of experiments involving, generally, regions other than the caudal peduncle. The most extensive of these was by Godsil (1936, 1938a, 1938b), who tagged 4,000 yellowfin and oceanic skipjack with opercular strap tags. Other experiments, involving relatively small numbers of fish, include bluefin tagged with opercular disks by Westman and Neville (1942), albacore tagged with button tags through the tail (Scagel, 1949), albacore tagged with "break-away" hooks (Partlo, 1950), albacore tagged with a Peterson tag through the base of the second dorsal fin (Powell, 1950), and albacore tagged with a plastic streamer tag (Schaefers, 1952).

According to Marr (in press):

"Large-scale tuna tagging experiments commenced with the development of the plastic loop or 'spaghetti' tag by Wilson (1953), following the earlier work of Alverson and Chenoweth (1951), Powell *et al.* (1952) and Schaefers (1952). This tag, a section of vinyl tubing, is applied through the muscle of the dorsal surface posterior to the second dorsal fin. The free ends are tied together after the tag is in place.

"Subsequent improvements, as judged by increased recovery rates, have arisen from modifications in (1) materials and methods of application resulting in longer tag life, (2) tagging technique resulting in a reduction of the time during which the fish is out of water and in the amount of handling to which it is subjected and (3) materials and techniques resulting in a greater recognition rate of recaptured fish.

"Modifications of the first type include the use of a clamp instead of a knot to secure the free ends of the tag, a tag core of monofilament nylon and the use of a different vinyl tubing capable of withstanding longer exposure to sea water (Schaefer, 1958).

"Modifications of the second type include not measuring the length of the tagged fish, the use of an automatic clamping device for securing the free ends of the tag (Schaefer, 1958) and the use of a dart tag (Yamashita and Waldron, 1958). With the dart tag, oceanic skipjack (*Katsuwonus pelamis*) can be hooked, tagged and released in as little as four to seven seconds (Waldron, personal communication), as contrasted to 20 seconds for loop tags (Yamashita and Waldron, 1959). Modifications of the third type include more conspicuous tag color (Blunt and Messersmith, 1960; Schaefer, 1958) and an attractive reward system (Schaefer, 1958)."

A stainless steel and plastic streamer dart tag has also been used by Mather (1960) and Mather and Bartlett (1962) to tag bluefin tuna and other large fishes without removing them from the ocean.

The dart tag is the most successful tuna tag yet developed. Tagging experiments on oceanic skipjack have shown a recovery rate with dart tags at least an order of magnitude greater than with loop tags (Blunt and Messersmith, 1960; Yamashita and Waldron, 1958). In view of the short period of time involved in catching, tagging and releasing an individual fish, it is unlikely that there will be any great improvements in this general type of tagging. Perhaps the next advance will involve tagging tuna in situ with radioisotopes, although there are obvious problems here.

2.3 Blood group systems

Although blood group systems in man have been known for over a half-century (Landsteiner, 1901), such systems have only recently been investigated in tunas, or in fishes, for that matter. Blood group systems are known to be under genetic control in every animal in which this question has been considered, including man, chickens, cattle, goats, rabbits, and goldfish. The methodology employed in the study of blood group systems is that of immunology.

The use of blood group system studies as a tool in identifying subpopulations has two important features. The first of these is that the characteristics studied are under genetic control. Thus, for the first time, it is possible to study genetic make-up directly and with assurance. In the case of morphometric characteristics, their genetic nature is assumed or hoped for. In the case of tagging experiments, only inferences about gene flow may be drawn (although in some cases the probabilities associated with such inferences are quite high). The second reason, following from the first, is that the power of this tool exceeds that of any other available tool. For example, it is not only possible to compare samples with respect to whether or not they represent the same subpopulation, but it is also possible to determine if a single sample represents a single subpopulation or a mixture of two or more subpopulations.

According to Marr and Sprague (in press):

"The methods of pursuing such studies are, as already indicated, through the techniques of immunology. Initially, the investigator must acquire a set of antisera or reagents that will identify one or more of the blood groups present in the species of interest. Such reagents may be developed by the introduction of red blood cells of the species being studied into other individuals of the same species, into individuals of other species, or more rarely, they may occur naturally in the same or other species. It has been found (Mäkelä, 1957; Bird, 1959) that extracts of the seeds of many legumes are very useful in this regard. The exact nature of the "antibodies" in the legume seeds is not known, but they are proteins, probably globulins (Boyd et al., 1958).

"Exploratory classification of samples of the species under study will proceed, of course, simultaneously with the development of antisera. At some point the investigator will be satisfied that the antisera can identify one or more blood groups and will begin to examine series of samples from appropriate localities. Since erythrocytes are frequently difficult to preserve for any length of time, this may mean quite literally taking the tests to sea.

"Through the use of this technique, samples of a subpopulation are not ordinarily classified according to the presence or absence of a single characteristic. In fact, most blood group systems are genetically quite complex, having more than two alleles; 6 - 9 alleles are not uncommon, and one blood group system in cattle has more than one hundred and fifty.[1] It follows, then, that samples are classified according to the frequency of presence or absence of several characteristics. Thus, in comparing samples, there still exists the problem (which fishery biologists constantly encounter) of making sample-size adequate to enable distinction between observational error and real differences between samples. . . .

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[1] "It should be pointed out that, lacking genetic information, the recognition of a particular blood group system as a 2-, 3-, 4-, or X-allele system is an assumption."

"There is a further quality of genetic characteristics which adds great power to the use of this tool. In the presence of random mating,[1] and assuming no mutation or selection effects, the frequencies of alleles p, q . . . x will occur in proportions according to the expansion of the binomial. This condition will obtain after only one generation of random mating and will persist thereafter. This general concept is known as the Hardy-Weinberg Law. It follows, then, that single samples can be examined to determine whether or not they conform to this law. If a sample does not conform to the Hardy-Weinberg Law, it may be concluded that it was not drawn from an interbreeding population; i.e., it was composed of individuals of two or more interbreeding populations. If a sample does conform to the Hardy-Weinberg Law, the data are consonant with the hypothesis and it may be concluded that the sample was drawn from an interbreeding population."

Marr and Sprague (in press) have summarized the advantages and disadvantages of the use of blood group systems in the study of subpopulations as follows:

"Advantages:

1. The characteristics studied are genetic.
2. Not only can samples be compared, but single samples can be examined with respect to whether or not they were drawn from a single subpopulation.
3. The statistical procedures involved are simple.
4. Recaptures (or a fishery) are not required.

"Disadvantages:

1. Blood preservation may be a problem. If it is, the method must be taken to sea.
2. Developing reagents may be difficult and time consuming.
3. In order for the full power of the technique to be realized, blood group systems must be identified and it must be possible to recognize one more phenotype than the number of recognized alleles. (This provides the degree of freedom necessary for Hardy-Weinberg analyses.)"

It should be pointed out that, lacking enough information for Hardy-Weinberg analysis, the danger of erroneous interpretation of blood group data exists. If, unknown to the investigator, individuals from two subpopulations mix during the non-spawning season and if the relative proportions of the two vary from area to area, it might be possible to observe significantly different frequencies, in different areas, of the blood group characteristics being studied. This possibility would be obviated if it were possible to restrict sampling to spawning assemblages. Moreover, in the one species (Sardinops caerulea) for which data bearing on this possibility exist, fish from two subpopulations may be found in the same geographic area, but not within the same school (see below).

2.4 Other methods

There are several other methods which have been, or might be, applied to the problem of identifying tuna subpopulations. Perhaps the commonest of these is the use of meristic characters, such as numbers of gill rakers, fin rays, finlets, etc. Where data on such characters have been examined, they have frequently been reported with morphometric data. The method of analysis is that of comparing frequency distributions.

Some work has been done at the species level, and might be applicable to levels of lesser differentiation, with serum protein antigens and soluble muscle tissue antigens through the use of the Ouchterlony method of diffusion precipitin analysis (Ridgway, 1962). It was concluded, however, that the use of serum proteins and muscle tissue was not as promising as the use of red blood cells (i.e., the study of blood group systems). There is the further question of whether or not these compounds (serum proteins and soluble muscle substances) are under strict genetic control.

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[1] "Random mating refers not to random mating between individuals, but rather to random combinations within a gene system."

Other work at the species level includes attempts to identify tuna larvae through paper chromatography extraction of amino acids (Matsumoto, 1960). The further application of this method is not indicated, since the amino acids present can be influenced by diet (Farris, 1957, 1958) and, in any case, the order of appearance of amino acids, rather than the kinds present, would be expected to be under genetic control.

Investigation of sperm morphology, through electron microscopy, as a possible means of distinguishing subpopulations is in progress (Inter-American Tropical Tuna Commission). These studies are not yet sufficiently advanced to demonstrate whether or not the method will have utility. In this same category is work in progress (California Department of Fish and Game) on the electrophoresis of soluble proteins from the eye lens. Similarly, Fujii et al. (1962) have examined the base composition of testis DNA of tunas.

Other methods, for example studies of parasite faunas, that have been applied to other species have not been used on the tunas.

3 IMPORTANT ADVANCES

3.1 Morphometrics

Important advances in the methodology of morphometric studies include (1) regression analysis of original variates rather than ratios, (2) the realization that overlapping distributions, even though significantly different, indicate the possibility of mixing and, in fact, that the amount of overlap sets an upper limit on the possible amount of mixing, and (3) the development of methods permitting the comparison of several characteristics simultaneously.

As for results, i.e., the definition of subpopulations, obtained with this method, it may be said that they have been somewhat equivocal. Perhaps the best evidence in support of this statement is the vigor with which other, more effective methods have been sought. Reference to the results of some of the morphometric studies of albacore, oceanic skipjack, and yellowfin in the Pacific will serve to illustrate the point.

In a preliminary study, based upon small numbers of fish, Godsil (1948) advanced the working hypothesis that the albacore taken off North America were "probably distinct and nonintermingling" with those taken off Japan. Subsequent tagging experiments demonstrate trans-North Pacific albacore migrations; blood group data support the hypothesis of a single North Pacific albacore subpopulation.

Hennemuth (1959) examined morphometric data on oceanic skipjack from French Oceania, the Hawaiian Islands, and the eastern tropical Pacific. No differences were observed between samples from French Oceania, nor between samples from the Hawaiian Islands. Differences were found between these areas, but it was not possible to rule out the possibility that these were "observer" differences. Differences were found between four areas in the eastern Pacific, as well as between these areas and the central Pacific area.

Hennemuth concluded:

"These morphometric comparisons of skipjack indicate that there is a lack of complete mixing of populations between the Central and Eastern Pacific, and that there is a lack of complete mixing among different areas in the Eastern Pacific. Whether or not some mixing between /the Central and Eastern Pacific/ and within the /Eastern Pacific/ occurs cannot be determined from these data, however, because of the small differences in body proportions with which we are dealing here, and because of the various sampling difficulties. It is doubted whether further investigations of racial structure of skipjack in these regions by morphometry will be very fruitful."

Tagging experiments have shown no interchange of skipjack between the Hawaiian Islands and the eastern Pacific. (The fishery in French Oceania is only at a subsistence level, so the chances of recovering tagged tuna there are slight.) Blood group studies demonstrate a difference between (1) the Hawaiian Islands, (2) the Society and Tuamotu Islands, and (3) the Marquesas Islands. (A comparison between these areas and the eastern Pacific has not yet been made.) Within the eastern Pacific area, tagging experiments have not shown exchanges between the areas separated by about 15° N. South of 15° N, tag recoveries indicate rather wide movements. North of 15° N, tag recoveries indicate much less movement. Nevertheless, Schaefer et al. (1961:358) apparently regard the oceanic skipjack of the eastern Pacific as part of a single subpopulation of much greater range:

> "The evidence for lack of far-westward migration of skipjack is much less impressive, and it is, in our opinion, quite possible that the skipjack population supporting the fishery adjacent to the American coast is only a portion of a population which ranges far to the westward."

Morphometric studies of yellowfin have been made by a number of people, including Godsil (1948), Schaefer (1952, 1955), Broadhead (1959), and Royce (in press). The general conclusion has been that there is little or no mixing between the eastern Pacific and other areas. Royce (in press) concluded, however, that limited mixing in an east-west direction along the equatorial region was possible, (for example, less than 50 percent overlap (= maximum possible mixing) between samples 1,500 miles apart), although the data did not show whether such mixing did in fact take place.

Godsil (1948) found differences within the eastern Pacific region but concluded that the yellowfin of that region were probably of a single subpopulation. Broadhead (1959) found differences between areas within the eastern Pacific region, but these were of the same magnitude as were found within areas. He therefore concluded that the yellowfin of the region belonged to a single subpopulation.

Yellowfin tagged in the eastern Pacific have not been recovered in other areas; the tagging results thus tend to confirm the distinctness of eastern Pacific yellowfin. Recoveries within the eastern Pacific, plus other data, have, however, led Schaefer (1961:75-6) to suggest the presence of two subpopulations in the eastern Pacific:

> "These data on yellowfin migrations, together with other knowledge (size composition of catch, spawning areas) lead us to suspect that we may be dealing with a northerly sub-population of yellowfin tuna which is largely confined to the region north of 15° N latitude, but some of whose members range some degrees further south, and another, southerly sub-population with its center off Central America, but ranging north to about 16° N and south to at least the vicinity of the Gulf of Guayaquil, there being an area of overlap of these population components along a stretch of coast in the vicinity of the Gulf of Tehuantepec."

In general, the author believes it is fair to state that because of sampling problems, measurement error, and inconclusiveness of results, attempts to distinguish subpopulations on the basis of morphometric characteristics are being abandoned in favor of other, more promising methods.

3.2 Tagging

Important advances in the methodology include (1) the development of the plastic, spaghetti tag and (2) the subsequent evolution of this tag, and of tagging methods, culminating in the plastic dart tag.

Perhaps the most spectacular advance in distinguishing subpopulations of tunas through tagging has been the results obtained from albacore tagging experiments in the north Pacific (summarized by Otsu and Uchida, in press; Clemens, 1961). Although the limited data do not establish conclusively the existence of a single subpopulation of north Pacific albacore, they do demonstrate trans-Pacific migrations. Furthermore, because of the tagging results, it has been possible to erect a model of albacore migration in the north Pacific, based on all available data, that is consonant with the existence of a single subpopulation. Limited blood group data support this hypothesis.

Equally suggestive, although based on much fewer data, are trans-Atlantic migrations of tagged bluefin tuna (Mather, 1960).

Much more extensive tagging experiments on oceanic skipjack and yellowfin have been carried out in the eastern tropical Pacific (Blunt and Messrsmith, 1960; Schaefer et al., 1961). The tagging results, although not necessarily the interpretation of the results, of these individuals are essentially similar. The work of Schaefer et al. (1961:357-9) may be quoted:

"One of the most striking and important results of the tagging of yellowfin and skipjack tunas in the region of the fishery off the coast of the Americas is the indication that they are much less migratory than might have been expected. Evidence from the tag recoveries is that they do not migrate, in large numbers at least, to other regions of the Pacific Ocean, and that, even within the Eastern Pacific region, the fish are not rapidly mixed.

"Through December 1959, we had recovered 747 tagged yellowfin tunas and 937 tagged skipjack. In addition, Blunt and Messersmith (1960) have reported the recovery of 263 yellowfin and 237 skipjack tagged in the Eastern Pacific. All of these have been recovered in the region of the fishery off the Americas; none has been returned from regions to the westward."

And:

"It is to be noted that a large share of our recoveries of yellowfin tuna and skipjack has been made within a few months of tagging. Yet a considerable number has been made a year or more after liberation. . . . If there were any very substantial portion of the fish tagged in the Eastern Pacific moving to other parts of the ocean where much fishing is done, we would expect to get at least a few recoveries from such regions.

"In the case of yellowfin tuna, the evidence of lack of significant migration far to the westward is fairly convincing. There is a substantial fishery throughout the Equatorial Central Pacific, regularly extending eastward to 110° or 120° W longitude, conducted by Japanese longline vessels, which would be expected to capture some of our tagged fish if they moved westward into that region. It is, of course, possible that too few of the small yellowfin we have tagged survive to reach the larger sizes taken on longline gear, or that tagged fish were captured on such gear but the tags were not returned to us. However, the negative evidence from the tag returns confirms the conclusion of independence of yellowfin stocks in the Eastern and Central Pacific. . . based on morphological differences.

"The evidence for lack of far-westward migration of skipjack is much less impressive, and it is, in our opinion, quite possible that the skipjack population supporting the fishery adjacent to the American coast is only a portion of a population which ranges far to westward. There is no substantial fishery for skipjack anywhere in the Central Pacific, except the rather minor fishery near the Hawaiian Islands. [Of some 13,000 skipjack tagged in the Hawaiian Islands region, about 10 percent have been recovered in that region, none elsewhere.] Such tagged skipjack as might migrate westward would thus have little or no opportunity to be captured. Nor have morphological studies revealed any indications of differences between the skipjack of the Eastern and Central Pacific (Hennemuth, 1959). [But see p. 7 above.] The western extent of the range of the skipjack population supporting our fishery remains, thus, an open question.

"Even within the range of the fishery in the Eastern Pacific, the migrations of these tropical tunas are rather less extensive than one might believe a priori. . . . At this time we wish to point out only the substantial share of the recoveries which have been made within fifty or a hundred miles of the tagging locality, even after many months at liberty. These tunas, at least at the sizes we have tagged, are obviously not roaming rapidly all over the range from California to Peru."

Schaefer's (1961) suspicion that there may be northern and southern subpopulations of yellowfin separated at about 15° N has already been quoted. The author has also pointed out that this same division is discernible in the skipjack tagging results.

While the evidence from tagging is much more definitive than that from morphometric studies, and in some cases is quite striking, it is nevertheless clear that we are apt to be dealing with complicated situations in nature and the results of tagging experiments may be expected to be equally complicated.

3.3 Blood group systems

In the opinion of the author the application of immunogenetic techniques to the study of subpopulations in tunas will prove to be the single greatest methodological advance in this area. The application of these techniques is so recent, however, that results are not yet abundant. But there are data available bearing upon the subpopulation problem in albacore, oceanic skipjack and bigeye.

Suzuki et al. (1959) presented data on a blood group system, designated Tg1-Tg2-O, in albacore from the northwestern Pacific (southeast of Honshu) and from the eastern Indian Ocean (largely southwest of Sunda Strait). The observed frequencies in the samples from the two areas showed striking differences. Marr and Sprague (in press) suggested that the data represent a three-allele system, analogous to the A-B-O system in man. Further, by Hardy-Weinberg analysis they showed that the North Pacific data represented a single subpopulation, while the Indian Ocean data represented a mixture of two or more subpopulations. This is in accord with the results of tagging experiments in the North Pacific. There have been no tagging experiments in the Indian Ocean.

Sprague (1961), reported on a blood group system, designated C, in albacore from the north and south Pacific. He believes this to be a two-allele system in which the phenotypes are either C-positive or C-negative. Samples from North America in 1960 and 1961 showed consistent proportions of the two phenotypes. A sample from Samoa in 1961 was significantly different. However, Dr. Sprague informed the author (personal communication) that subsequent work and additional samples and reagents suggests that a greater number of alleles is involved and a separation merely on the basis of proportions of C-positive and C-negative is not as clear-cut as first appeared to be the case.

Sprague and Holloway (in press) and Sprague, Holloway and Nakashima (in press) have presented information on blood group studies of oceanic skipjack, albacore, bigeye and yellowfin. Their data were adequate to consider the subpopulation problem only for oceanic skipjack and bigeye. On the basis of phenotype frequencies in a system in oceanic skipjack termed the B system, differences were found between (1) the Hawaiian Islands, (2) the Marquesas Islands, and (3) the Tuamotu and Society Islands. They interpret the data as indicating the existence of three subpopulations. However, as they suggest, since the data do not permit Hardy-Weinberg analysis, a minimum of two subpopulations could be involved, mixing to varying degrees in the three areas. This is probably unlikely, but is a possibility.

A three-allele blood group system analogous to the human A-B-O system has been found by Sprague et al. (In Press) in bigeye. This system has been termed the A-B-O system (although it is not related to the human A-B-O system except by analogy). Data from the Hawaiian Islands permit Hardy-Weinberg analysis, and it was thus possible to show that the sample represented a single subpopulation.

Although not concerned with tunas, two additional studies of blood group systems in fishes may be mentioned. The first of them (Sindermann and Mairs, 1961) describes a three-allele A-B-O analog in the spiny dogfish. The observed frequencies conformed to the Hardy-Weinberg Law; the sample represents a single subpopulation. The interesting feature of this work is that it was possible to compare the blood types of pregnant females with those of their unborn pups. The results of these comparisons were consonant with a three-allele system.

The other study (Sprague and Vrooman, in press) provides information on subpopulations of the sardine of the northeast Pacific. Because of these blood group data and other kinds of data (tagging experiments, space-time distribution of spawning, etc.), more is known about the subpopulation structure of this species than of any other fish. The possible existence of subpopulations has been recognized for some time (Marr, 1957) on the basis of the existence of four space-time spawning groups. Sprague and Vrooman were able to identify two subpopulations on the basis of a C blood group system. These probably correspond to the fish spawning off southern California and those spawning off central Baja California. It is understood (press release dated April 13, 1962) that sardines in the Gulf of California have recently been found to be characterized by different proportions of C-positive and C-negative fish than the previously identified subpopulations.

It is known from these blood group data and from tagging experiments that fish from the two subpopulations off southern California and Baja California may occur in the same geographic area, probably at or about at the same time. However, they apparently do not occur in the same schools, since no schools have been found to contain intermediate proportions of C-positive and C-negative fish. The reason for this apparent lack of intra-school mixing even during the non-spawning period is not known but may be related to the facts that (1) sardines tend to school by size and (2) northward migrations tend to be size-specific, so that fish of the same size from the two subpopulations may not occur in the same area at the same time.

Continued exciting results may be expected from the application of this technique to the problem of distinguishing tuna subpopulations. It is to be hoped that knowledge of the blood group systems used will be such that Hardy-Weinberg analyses will be possible and that each subpopulation will be identified by more than one blood group system.

4 REMAINING PROBLEMS

Although a promising start has been made on the identification of tuna subpopulations, the main tasks of identification and range delimitation lie before us. These problems still exist for all tuna species in all oceans.

If the kinds of remaining problems are categorized, the first is that of improving methodology. This is not so much a matter of improving present methods as it is developing completely new methods or, as is more likely, adopting methods presently being used in other fields. As useful as tagging experiments and immunogenetic studies may be, it should be kept in mind that different methods may offer other advantages.

The second category, as already indicated, is that of identifying subpopulations and delimiting their ranges, for all tuna species in all oceans. This is obviously a goal that will not be soon attained. Some choices will have to be made in the order in which these many problems will be attacked; specifically, what species in what localities will be studied first. The choices may be dictated by economic (i.e., fishery) problems. Examples of tuna subpopulation problems, the solution of which would have reasonably immediate applications, include the yellowfin of the eastern Pacific, the albacore of the North Pacific, and the oceanic skipjack of the Hawaiian Islands region. Undoubtedly there are other examples.

On the other hand, a good case can be made for basing the choice of which problem to attack first on the one considered most likely of solution. If there is a tuna subpopulation problem which present knowledge and judgment indicates is most susceptible of solution, enough might be learned in its solution to increase the rate of solution of similar problems attacked subsequently. A problem selected on this basis might or might not coincide with one selected on an economic basis.

The third category is that of the application of the knowledge of subpopulations in the study of other problems. Foremost among them are the fishery-oriented problems which, in fact, give rise to the study of subpopulations. These include the population dynamics of subpopulations and the equally important, but perhaps less well appreciated, ecology of subpopulations.

Other problems, of less immediate application but certainly of long range importance, include in situ studies of population genetics, studies of tuna genetics, and studies of comparative evolution. It is to be hoped that basic studies such as these will not be overlooked as a result of the pressure of more immediate problems.

Methodological Paper No. 3

SIZE AND COMPOSITION OF TUNA STOCKS

By

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Abstract

The present paper is a review of methods used and results obtained in estimating vital statistics of tuna populations. The age of four of the major tuna species: bluefin, yellowfin, albacore and skipjack, has been determined by counting concentric rings in vertebrae (section 2.1.1). For the three former species and bigeye tuna, also scales have been found usable for age determination (section 2.1.2). However, students differ in their opinions about the readability and the interpretation of the observed zones.

The growth estimates derived from reading of marks in hard parts of the fish, and by size frequency analysis coincide fairly well with regard to bluefin and albacore. In the case of yellowfin and skipjack, which are mostly restricted to the tropical seas, the growth rate deduced on the basis of the former technique is considerably slower than that deduced from other methods including tagging experiments.

From records of Japanese commercial catches, mortality rates of bluefin, yellowfin, albacore and skipjack have been investigated. Similar estimates of Eastern Pacific yellowfin are obtained from American records. The estimates are derived from the abundance of age groups, employing the formulas (6.7), (6.8) and (6.9) for the numerical calculations.

DIMENSION ET COMPOSITION DES STOCKS DE THON

Résumé

Cet article traite des méthodes d'établissement des statistiques des populations de thon et des résultats obtenus. La détermination de l'âge des quatre espèces principales de thon, thon rouge, thon à nageoires jaunes, thon germon et bonite à ventre rayé, a été effectuée par comptage des cercles concentriques dans les vertèbres (2.1.1). Pour les trois dernières espèces et le thon obèse, les écailles également se sont montrées utiles à la détermination de l'âge (2.1.2). Cependant les opinions des chercheurs diffèrent sur la possibilité de lecture et sur l'interprétation des zones observées.

Les estimations de la croissance, d'après la lecture des marques dans les parties dures du poisson et d'après l'analyse de la distribution des tailles, coincident assez bien pour le thon rouge et le thon germon. Dans le cas du thon à nageoires jaunes et de la bonite à ventre rayé, qui sont surtout cantonnés dans les mers tropicales, le taux de croissance déduit depuis les résultats de la première de ces techniques est considérablement plus lent que celui qu'on peut obtenir avec les autres méthodes, y compris les expériences de marquage.

On a étudié les taux de mortalité du thon rouge, du thon germon et de la bonite à ventre rayé d'après les données des pêches commerciales japonaises. Des estimations identiques ont été effectuées sur le thon à nageoires jaunes du Pacifique oriental d'après les données américaines. Les résultats sont dérivés de l'abondance des groupes d'âge, en employant les formules (6.7), (6.8) et (6.9) pour les calculs numériques.

DIMENSIONES Y COMPOSICION DE LAS POBLACIONES DE ATUN

Extracto

Se reseñan en esta ponencia los métodos empleados para estimar las estadísticas biológicas de poblaciones de atún y los resultados obtenidos. La edad de las cuatro especies principales: atún de aleta azul, atún de aleta amarilla, albacora y barrilete se ha determinado contando los anillos concéntricos en las vértebras (2.1.1). En el caso de las tres primeras especies y en el del patudo también se han empleado las escamas para determinar la edad (2.1.2). Empero, los investigadores no están de acuerdo sobre la legibilidad e interpretación de las zonas observadas.

Las estimaciones de crecimiento deducidas de la lectura de marcas en partes duras del pescado y del análisis de la frecuencia de tallas, coinciden bastante en lo que se refiere al atún de aleta azul y a la albacora. En el caso del atún de aleta amarilla y del barrilete, circunscritos principalmente a los mares tropicales, la velocidad de crecimiento deducida por la primera técnica es mucho más lenta que la deducida por otros métodos, inclusive los experimentos de marcado.

Se han investigado las tasas de mortalidad del atún de aleta azul, atún de aleta amarilla, albacora y barrilete a la vista de los registros de las capturas industriales japonesas. Estimaciones análogas del atún de aleta amarilla del Pacífico oriental se obtienen de registros norteamericanos. Las estimaciones se basan en la abundancia de grupos de edad empleando las fórmulas (6.7), (6.8) y (6.9) para los cálculos numéricos.

1 INTRODUCTION

Under natural conditions, without a fishery, the total weight of a fish population may increase and become, on the average, stabilized at the highest level permitted by the environment. At this stage the increase in weight represented by recruitment and individual growth is compensated by the natural mortality (Russel 1931, Thompson 1937). To this maximum level in weight of the whole population, corresponds a maximum average age of the fish. By adding to the natural mortality a constant removal of fish due to fishery, the weight of the population may be reduced and stabilized at a lower size level, at which the sum of natural and fishing mortality equals the recruitment and growth. At this equilibrium, the fishing mortality has been termed "equilibrium catch" or "equilibrium yield". The most rational utilization of the population may be obtained by increasing the fishing mortality to the point at which the stock produces the maximum equilibrium yield, also termed the maximum sustained yield.

An additional effect of fishing is a change in the age and size composition of the population because the average age may be reduced by the higher mortality rate following the exploitation. Consequently the effect of fishing upon an unexploited fish population may be deduced by (a) investigating the variations in population size, and (b) examination of the size composition. This requires mathematical models, which describe the relationship in question. For the former case, Schaefer (1954, 1957) has developed an analytical formula combining yield, population size and intensity of fishing. This model is employed in population dynamic studies of the Eastern Pacific fishery for yellowfin and skipjack using records of catch and effort as basic data. The other way of investigating the dynamics of a fish population is expressed in mathematical terms by the analytical model of Beverton and Holt (1957). In this formula the yield is given as a function of independent parameters for recruitment, growth and mortality. These parameters are known as the "vital statistics" and determine the size composition of a population.

The present paper is a survey of the literature on the estimation of vital statistics of tuna populations, reviewing the principal methods employed, and summing up the main results obtained. Due to the limited time allocated for this study, there are several papers on the items concerned which have not been available for incorporation. However, the main purpose of the present contribution is to review the methodological problems encountered in this field, and discuss them. The species referred to in this report are as follows:

English name:	Scientific name:
Bluefin tuna	Thunnus thynnus (Linnaeus)
Yellowfin tuna	Neothunnus albacora (Lowe)
Albacore	Thunnus alalunga (Bonnaterre)
Bigeye tuna	Parathunnus obesus (Lowe)
Skipjack	Katsuwonus pelamis (Linnaeus)

2 METHODS OF AGE DETERMINATION

Knowledge of the age of the fish is necessary for solving such fundamental biological questions as life span, growth and recruitment. For determining age, two general methods are available; (a) interpretation of zone structure in hard parts of the fish, and (b) analysis of size-frequency distributions. The former method is anatomical in nature and requires studies of the individual fish. The latter is a statistical method based upon the size relationship within the population and requires large random samples. Both methods are used in age analysis of tuna.

2.1 Zone Structure in Hard Tissue of Tuna

Counting of zones is the method most used in determining the age of fish inhabiting the temperate and cold waters where temperature and food fluctuate considerably with the seasons. These seasonal fluctuations are reflected as different layers in the hard tissue due to alternating stagnation and increase in the growth rate. In spite of the fact that seasonal fluctuation of environment factors is not appreciable in the tropical and subtropical sea areas, fairly conspicuous zone structures have been described in scales and vertebrae of tropical tuna species such as yellowfin and skipjack. However, students differ in their opinions about the readability and the interpretation of the zones.

2.1.1. Zone Structure in Vertebrae

In four of the major tuna species the age has been determined by counting the concentric rings in vertebrae:

Bluefin	Mediterranean: Sella (1930). Atlantic: Rodriguez-Roda (1960), Hamre (1958), Vilela (1960), Mather and Schuck (1960). Pacific: Aikawa and Kato (1938).
Yellowfin	Pacific: Aikawa and Kato (1938).
Albacore	Atlantic: Figueras (1957). Pacific: Uno (1936a, 1936b), Aikawa and Kato (1938), Partlo (1955).
Skipjack	Pacific: Aikawa (1937b), Aikawa and Kato (1938).

Investigating vertebrae of albacore caught off Hawaii, Otsu and Uchida (1958) concluded that the albacore from this area could not have their ages determined from vertebrae by the existing techniques. In a later study (1959) they also examined scales and a number of other bone structures for possible indications of age, but with the same negative results. The authors remarked that although the vertebrae of small albacore were somewhat more readable than those of large albacore, it was still not possible to achieve sufficient consistency in ring counts and measurements.

Most of the investigators have used prehaemal vertebrae in their attempts of age determination in tuna species. The rings do appear, however, also in other parts of the vertebral columns (Otsu and Uchida 1958; Mather and Schuck 1960). The frequent choice of prehaemal vertebrae may be due more to practical considerations than to actual advantages concerning the readability of the zones. The vertebrae of the species in question are amphicoelous. The zones occur as concentric rings running on the concave surface parallel to the outer margin of the centrum. When the bone is cleaned and dried, the rings may appear as narrow translucent zones corresponding to ridges on the surface, separated by broad opaque zones. In order to improve the definition of the zones of bluefin vertebrae, Galtsoff (1952) proposed to stain the vertebrae with a stock solution of alizaron and preserve them in glycerol. The method is based upon the observation that this dye has a great affinity to calcium phosphate, and that the intensity of staining is correlated to the concentration of this salt (Hollister 1934). Assuming that a certain layer of a ring, accentuated by this staining method, is laid down at a definite period of the year, one may conclude that the seasonal variation in the concentration of this salt deposited in the bone is, at least in part, responsible for the ring formation.

Some investigators have later employed the alizaron method with success (Hamre 1958, Mather and Schuck 1960) while other students have found this staining procedure disappointing (Otsu and Uchida 1958, Vilela 1960). If the vertebrae are to be sectioned, the preservation in glycerol is no doubt unpractical. In order to accentuate the ring on sectioned bones, Partlo (1955) immersed the objects in one percent KOH, washed them in tap water and preserved them in 95 percent alcohol.

The vertebral surface are usually examined under magnification but often the rings may be counted with the naked eye.

2.1.2. Zone Structure on Scales

References to age-analyses of tuna by means of scale readings of Atlantic bluefin are found in Westman and Gilbert (1941), Westman and Neville (1942), and Mather and

Schuck (1960). Hayashi (1958), in his comprehensive work on age determination of Pacific tuna, reports that Nose and Hiyama (?) have examined the age of Pacific yellowfin, albacore and bigeye tuna with success by means of scale reading. It has however been observed (Otsu and Uchida 1959) that albacore scales removed from the same fish were often variable in size. As small scales also contained fewer rings than large scales, the authors concluded that the origin of the scales may not be uniform in this species.

The scales of tuna are of the cycloid type. Only scales from the posterior part of the fish are found usable. The anterior scales are thick and non-transparent and show no regular zone structure. Westman and Gilbert (1941) suggested that scales of bluefin from the region of the second dorsal fin are the most suitable for reading while other investigators have preferred scales from the area under the caudal peduncle. The scales are cleaned, dried and mounted on glass slides and examined with the aid of a binocular microscope. Mather and Schuck (1960) employed the method of celluloid impression. This method records the sculpturing of the scale and is recommended when the scales are thick and non-transparent.

2.1.3. Interpretation of the Rings Observed

In all attempts at determining the age of fish by the method of counting marks on scales and bones, the prime question is whether the zones reflect seasonal alternating growth phenomena or whether they are nothing but simple growth marks. In the case of tuna species this question is still unsolved. Indications of an annual ring formation in hard tissue of bluefin and albacore have been obtained by comparing growth derived from studies of vertebrae to that estimated from size frequency analyses (Hamre 1958, Mather and Schuck 1960, Partlo 1955). A more direct way to obtain evidence to verify the vertebral and scale-reading method is to determine the time of ring formation. If the rings are laid down regularly and once each year a study of the seasonal change in the marginal character of the scales and vertebrae collected periodically throughout a year should indicate the time or season at which the rings are completed.

Nose et al (1955) investigated the time of ring formation in scales of yellowfin, albacore and bigeye tuna. The studies were based upon measurements of the marginal increment throughout a year, expressed by an index

$$G = \frac{T - R_n}{\frac{1}{2}(R_n - R_{n-2})} \qquad (2.1)$$

where T designates the length of the scale measured from focus to the margin, and R the distance from focus to the n-th ring. The rings were described as concentric transparent rings. The time when the index is nearest to zero should be the time when the last transparent ring was completely formed. This is clear when measuring the scale of a single fish. However, during the time of ring formation it may happen that some of the individuals have made a new ring but others have not, and the average index of a sample may show no ring formation. In order to determine the proportion of individuals which form a ring at a certain season it is therefore necessary to examine the size frequency of the index. Nose et al (1955) utilized a Fourrier's analysis for this purpose and concluded that the proportion of individuals forming rings had more than one maximum throughout a year. Yellowfin had one maximum in spring and one in winter, albacore had one in early summer and one in winter, and bigeye had four maxima during the year concerned. The authors interpret the result as follows: If all the individuals form only one ring a year, there must exist within the species groups which have different seasons of ring formation. Another possibility is that the scale forms a ring more than once in a year. The authors regard this as less likely, but emphasize that the basic data were insufficient for obtaining a clear answer.

Otsu and Uchida (1959) made an attempt to obtain indication of the time of ring formation in vertebrae of albacore. The difference between the marginal radius (T) and last ring radius (R_n), measured from the midpoint of the centrum, was considered the marginal increment. The index

$$G = \frac{T - R_n}{T} \quad (2.2)$$

plotted against the month of capture resulted in a random scatter of points indicating no regularity in the time of ring formation. Although it was realized that the validity of the method was questionable since the rings on the margins were frequently indistinct, the authors were inclined to regard the rings on albacore vertebrae simply as growth marks which are laid down randomly with regard to time.

2.2 Size Frequency Analysis

The method of deriving estimates of the age-size relationship of fish by size frequency analysis was originally described by Petersen (1892) in growth studies of plaice. It has later become a frequently accepted method in age studies of marine animals, especially in cases where zone structure of hard tissue is lacking or found difficult to interpret. The method has further been employed as a check to the validity of reading annulae. The technique used is based upon the observation that, within a population with restricted spawning time, the size of fish of equal age tend to form a normal distribution. From successive modal size groups it is possible to determine relative age while absolute age of a size group can only be determined when the sample contains all younger age-groups. Assuming that the age-groups are normally distributed, the following factors influence the size composition pattern of a sample containing several age-groups:

(a) Number of age-groups.

(b) The relative strength of the age-groups.

(c) The average yearly increments.

(d) The standard deviations of the age-groups.

Theoretical considerations of how these factors may act upon the size composition of samples have been published by several authors, amongst others by Lea (1924) with respect to herring investigations. This method of separating age-groups is adequate when the modal size groups do not overlap each other too much. As overlapping is due to increasing standard deviation and decreasing yearly growth, and as these figures are positively correlated to increased age, the method usually fails to separate older age-groups with certainty.

Despite the fact that the tropical tuna species may spawn over a fairly wide period of the year, distinct size groups do appear in the catches and agreement in modal size of fish caught in different years indicate age-groups. In studying modal size groups of Eastern Pacific yellowfin, Hennemuth (1961) pointed to the following basic concept of year-classes: (a) the modal length increased in a regular fashion with time; (b) there was good agreement in length of fish in the same relative age-group in different years; (c) there was generally agreement in the extent of growth of different year-classes in the same years; and (d) abundance or scarcity of year-classes persist in successive months and years.

The observations of clear cut modal size groups within tuna populations indicate that, although the species may occur with ripe gonads over an extended period of the year, the amount of spawning or survival of the larva must have a distinct optimum at a certain limited season.

2.2.1. Methods of Separating Age-Groups

Supposing that the size within age groups is normally distributed, the methodological problem in deriving age estimates from frequency curves is to decomponate the total curve in normally distributed component curves representing the age-groups present. The problem has been investigated mathematically but this analysis is very complex and solutions have only been found in cases of special bimodal distribution (Gottschalk 1948).

In works on albacore, Suda (1954, 1955) established different normal distributions by altering the factors a - d (2.2) and selected those which fitted best to the distribution concerned. The fit was tested by the X-square test. By a graphical method developed by Harding (1949) it has become possible to obtain approximate estimates of relative strength, average size and standard deviation of age-groups constituting the total distribution. The method makes use of the probability graph paper devised by Hazen (1913) and has been used with success in cases where the component curves do not overlap too much. It has further been realized that, in cases where overlapping is considerable, the method provides valuable indication of the magnitude of the parameters of the normal distributions in question. This technique of breaking down a multimodal frequency curve in normally distributed component curves was employed by Partlo (1955) in separating age-groups of albacore. The author concluded that, although an albacore population would be unlikely to consist of completely normal size groups, the method seems justifiable as a simple interpretation of the available data.

Another method of separating age-groups was described by White (1936) for salmon parr and has recently been applied to bluefin tuna by Tiews (1960). Plotting eye diameter against fork length of 1607 bluefin caught in the North Sea, Tiews shows that the plots fall along three oblique and parallel lines. The average length of the fish within each group, separated by the graphical representation of the data, corresponds with average length of 12, 13 and 14-year-old bluefin found by Sella (1930).

3 METHODS OF CALCULATING GROWTH

3.1 Definitions of Growth

Growth may be defined quite simply as an increase in size, growth rate as size increment per unit of time. In terms of length the growth rate has been defined as follows:

$$h = \frac{l_t - l_o}{l_o} \qquad (3.1)$$

and

$$e^{kt} = \frac{l_t}{l_o} \qquad (3.2)$$

where l_o is initial length, l_t the length at time t.
h is known as the relative growth rate, k as the coefficient of instantaneous rate of growth. Hence the relation between k and h is:

$$k = \frac{1}{t} \log_e \frac{l_t}{l_o} = \frac{1}{t} \log_e (h+1) \qquad (3.3)$$

For $t = 1$ the formulas define the annual growth rate.

Growth is usually illustrated graphically by plotting observed size against age. The resulting diagram is known as the growth curve.

3.2 Age Data

When age is determined the average size at successive ages can be used directly to estimate growth rate and to determine the growth curve. This method requires large random samples of the population. Less subjected to sampling error is the method of back calculating individual growth which was applied to scombroids by Aikawa (1937a). As basic data, Aikawa used measurements of the vertebral centrum and the length of the fish:

$$l = aT + b \qquad (3.4)$$

where l is the length of the fish and T the distance from the center to the outer edge of the vertebral centrum. The linear relationship, if such exists, is usually determined by plotting observed l on T, fitting a straight line to the points using the least square method. If R_n is the distance from the center to the nth ring and l_n the length when this ring was formed, we have, by putting $T = R_n$ in (3.4):

$$l_n = aR_n + b \quad (3.5)$$

For b = 0, the formulas (3.4) (3.5) give:

$$l_n = \frac{1}{T} R_n \quad (3.6)$$

which is known as the direct proportion formula for back calculation of body length. In cases where rings are formed once a year then the estimates of l_n can be used to determine the yearly growth of the fish prior to capture.

3.2.1. Length/Weight Relationship

The formulas (3.5) (3.6) provide growth estimates in terms of length. Converting to weight, Aikawa and Kato (1938) employed the cube relationship:

$$w = Cl^3 \quad (3.7)$$

The letter C, determined by corresponding length/weight measurements, is known as the condition factor and may fluctuate with regard to individuals. C is especially influenced by the yearly reproduction cycle. Using the cube law for calculating unknown weight from known length, one has made the presupposition that the fish has unchanged body form throughout life. But fish may change the body proportion with increasing size and a better approach to the length/weight relationship is obtained by the formula:

$$w = Cl^n \quad (3.8)$$

C and n are usually calculated from the logarithmical expression of (3.8)

$$\log w = \log C + n \log l$$

by plotting log w on log l and fitting a straight line to the points using the least square method.

3.3. Progression of Modal Size Groups

Another commonly accepted method of obtaining growth estimates of tuna species is by measuring the progression of modal size groups as they pass through the fisheries. The basic data are individual, size range of which are usually chosen from 2 to 5 cm and likewise in kg. Criteria for locating modes are proposed by Moore (1951), Iversen (1956) and Hennemuth (1961). The method requires random samples of the population, collected periodically.

3.4. Tagging Experiments

The most direct method of estimating growth is by accurate size records of released and recaptured tagged fish. However, due to difficulties in tagging and measuring tuna without injuring them, few growth data have so far been obtained by this method. In order to save time during tagging, the tagged fish have in some cases not been measured individually but their average size valued on the basis of measurements of samples from the school in which the tagging was conducted (Otsu 1960, Yamashita et al 1959). In other cases the length is estimated to the nearest 5 cm (Schaefer 1960). The authors remarked that this may lead to error in the growth estimates, but the error may be averaged out if a sufficient number of long term tag recoveries are available.

3.5. Theoretical Growth Curves

Several attempts have been made to find a general function which fits well to the empirical growth curve of animals. A general mathematical expression of size as a function of age is of especial value in growth studies when only segments of the growth curve can be determined empirically as the function may assist in interpolation and extrapolation. It may further serve as a basis to compare observed differences in growth phenomena and may serve as a test of the observations. Finally, an analytical formulation of the growth is necessary for incorporation of growth into the equations of population dynamics theories which are based upon the vital statistics.

3.5.1. Von Bertalanffy's curve

The theoretical growth curve of Von Bertalanffy is expressed by the formula:

$$1_t = L_\infty (1 - e^{-k(t-t_o)}) \qquad (3.9)$$

where 1_t is the length at age t. L_∞ designates ultimate length, usually named as asymptotic length, and k the coefficient of instantaneous growth rate (3.2). t_o may be regarded as the apparent age at length zero. In terms of weight using the cube law, (3.9) may be written:

$$w_t = W_\infty (1 - e^{-k(t-t_o)})^3 \qquad (3.10)$$

The asymptotic weight W_∞ may be estimated from L_∞ after the formula (3.8).

These equations describe the growth in length and weight as a function of age by the four parameters k, W_∞, L_∞ and t_o which are the growth characteristics of a species. The Von Bertalanffy's growth curve has frequently been found to provide a satisfactory approach to empirical growth data of fish species. Particular attention has lately been paid to the formula (3.10) as this is incorporated in the analytical population modal described by Beverton and Holt (1957).

The best approach in obtaining estimates of k, L_∞ and t_o is from the logarithmical expression of (3.9) (Beverton 1954):

$$\log_e (L_\infty - 1_t) = \log_e L_\infty + kt_o - kt \qquad (3.11)$$

A trial value, L_∞, can be derived from a freehand Walford graph (3.4.2). The plotting of $\log_e (L_\infty - 1_t)$ to t should be a straight line where straightness is sensitive to changes in L_∞. When the best L_∞ is selected, k is determined from the slope of the corresponding line. Intercept of y-axis is equal to $\log_e L_\infty + kt_o$ from which t_o can be calculated.

3.5.2. The Walford Graph Transformation

Plotting length at age t against length at age t+1, the points above the inflection will approach a straight line. This line is known as the Walford graph transformation of the typical growth curve and was described empirically by Walford in 1946. The ultimate length ($1_{t+1} = 1_t$) is the point at which the line cuts the 45° diagonal through origin, the slope of the line gives the growth rate. If this is termed K, it can be shown theoretically that the parameter k in (3.9) is equal to $-\log_e K$ (Ricker 1958). The Walford graph transformation is a frequently accepted technique in interpolating and extrapolating growth data of fish species and may be used in determining the growth parameters of the curve of Von Bertalanffy.

3.5.3. The Gompertz Function

For expressing the ideal growth curve of organism, Riffenburgh (1960) recommended the Gompertz function

$$1_t = ab^{c^t} \qquad (3.12)$$

and described a new method for obtaining estimates of the parameters a (asymptotic length), b and c. Considering three pairs of data for 1 and t(t=i, t=i+j and t=i+k, j > 0, and k = 2j), he arrived at three equations from which successive estimates of c, b and a could be obtained.

$$c^j = \frac{\log \frac{l_i + k}{l_{i+j}}}{\log \frac{l_{i+j}}{l_i}} \qquad (3.13)$$

$$\log b = \frac{\log \frac{l_i + k}{l_{i+j}}}{c^{i+j}(c^j - 1)} \qquad (3.14)$$

$$\log a = \log (l_i + l_{i+j} + l_{i+k}) - \log (b^{c^i} + b^{c(i+j)} + b^{c(i+k)}) \qquad (3.15)$$

Two methods, termed the long and the short method were given to incorporate empirical data in (3.13), (3.14) and (3.15). The long method provides estimates which converge in probability to the parameters as the sample size grows large but involves a great deal of numerical calculation. Using the short method, any three pairs of data may be chosen and a, b and c estimated directly from the equations. The latter is the most rapid method but is considerably less accurate.

4 GROWTH ESTIMATES OF TUNAS

4.1. Bluefin Tuna

By the method of counting rings on vertebral faces, Sella (1930) determined the age of more than 1,500 bluefin caught in the Mediterranean. His data included the age-groups I to XIV. Using the same technique, later investigators (Hamre 1958, Rodriguez-Roda 1960, Vilela 1960) have obtained results which coincide fairly well with those of Sella. Size frequency analyses of German (Tiews 1957) and Norwegian (Hamre 1958) caught bluefin have further shown dominating size groups which progress in close agreement with the growth rate deduced by Sella.

In a recent work, Mather and Schuck (1960) determined the growth curve of western Atlantic bluefin up to 12 years. The authors employed the method of counting rings in scales and vertebrae, and the growth estimates obtained were tested by size frequency analyses, and by two long-term tag recoveries. The data were fitted to a Walford graph transformation starting from a point of 3 years old. The curve obtained was found to fit well to earlier estimated growth data by Westman and Neville (1942) and to the growth of Eastern Atlantic bluefin. The growth curve is plotted in Fig. 1. (1).

Employing the technique of back calculating body length by measuring rings on vertebrae, Aikawa and Kato (1938) estimated the growth rate of five bluefin caught in Japanese waters. Prior to this work, Kishinouye (1923) and Kimura (1932) had traced growth of Pacific bluefin on the basis of size composition analyses. Kishinouye arrived at a growth rate somewhat similar to that of yellowfin for the first 3 years (Fig. 1, curve 2). Aikawa and Kato's results are in fairly good agreement with the growth rate estimated by Kimura. The growth curve determined by these authors starts at 26 cm for 1-year-old fish, and indicates that the Pacific bluefin have a somewhat more rapid growth than the bluefin in the Atlantic.

4.2. Yellowfin Tuna

Kishinouye (1923) studied the size distribution of small yellowfin and concluded that in their early years the fish increase in size at a rate similar to that found for bluefin. Schaefer (1948) studied size groups of Pacific yellowfin in Central American waters. Later, Moore (1951) analysed modal weight groups of bait boats (small fish) and longline (bigger tuna) catches of yellowfin caught in Hawaiian waters and found good agreement with Schaefer's data. Fitting the data to a Walford line, Moore estimated the asymptotic length to be 190 cm. Riffenburgh (1960) used Moore's data as example to estimate the parameters in the Gompertz function (3.12) and arrived at the equation:

$$l = (164,78)\,(0,17468)^{(0,91770)^{(t+16)}}$$

using his short method (l = cm, t = months). Iversen (1956) investigated size frequency of Pacific yellowfin, agreeing in general with the growth rate described by Moore. Analysing modal size groups from Japanese bait boat (40 to 80 cm) and longline (80 to 160 cm) catches, Yabuta and Yukinawa (1957) regard the growth curves derived from the two sets of data as two segments of a continuous growth curve for the species. The segments combined correspond remarkably well to the growth curve found by Moore. The curve is plotted in Fig. 1. (2).

According to Hennemuth (1961), the growth estimated from modal progression observed in purse-seine and bait-boat catches of Eastern Pacific yellowfin fit to the theoretical curve of Von Bertalanffy (3, 9) within the size range of the available data (70 to 140 cm). The calculated parameters were on the average $k = 0.05$, $L_{\infty} = 169$ cm, $W_{\infty} = 99$ kg, $t_o = 10$ months. In term of length the curve is shown in Fig. 1 (3). As it appears from the figure, the author remarked that the Hawaiian and Japanese longline-caught fish seem to be somewhat larger for their age than the yellowfin in the Eastern Pacific bait-boat and purse-seine catches. In the Eastern Pacific the longline catches are insignificant and have not been analysed. The growth estimates derived from tagging of Eastern Pacific yellowfin indicate a little lower growth rate than that deduced from size frequency analyses (Schaefer 1961). The authors referred to above agree that the yellowfin is a very rapid growing species and has a relatively short lifespan.

Other investigations have, however, arrived at considerably different conclusions to the questions concerned. Employing the same technique as for bluefin, Aikawa and Kato (1938) arrived at a constant yearly increment of about 15 cm for yellowfin between 1 and 5 years old. One-year-old fish were estimated to be 40 cm. In a prior work on size frequency of yellowfin, Kimura (1932) had deduced a similar growth rate. According to Hayashi (1958), Nose and Hiyama (?) have determined a still lower growth rate of this species using rings on scales as basic data for their study. The growth estimates of the three latter publications do not lie far from curve 4 in Fig. 1, which is constructed on the basis of size analyses of Atlantic yellowfin caught in waters adjacent to Cape Verde (Postel 1959). According to these findings, the yellowfin is a slow-growing and long-living fish.

4. 3. Albacore

Studying size frequency of young albacore, Kishinouye (1923) deduced a similar rapid growth rate as that found for bluefin and yellowfin.

Other students dealing with growth of this species report a considerably slower growth rate. Uno (1936a, 1936b) counted vertebral rings of Japanese pole-and-line caught albacore, and separated three age-groups (IV, V, VI), with size distributions coinciding with the modal size groups in the catches. Using the same technique as for bluefin, Aikawa and Kato (1938), determined the growth of albacore up to 8 years of life. Investigating length composition of longline-caught albacore in the Pacific north of 26°N, between 130°E and 170°W, Nakamura *et al* (1953) observed a discrepancy in the position of modes comparing data from two successive years. As probable causes there were mentioned: (a) difference in annual growth rate; (b) difference in annual propagation; (c) difference in annual course of migration. The data show six modal size groups, located at approximately equal intervals. On the basis of size composition of longline-caught albacore in the North-west Pacific, Suda (1954) arrived at a similar result and concluded that, if the modal size groups represented year-classes, the growth rate of albacore is nearly constant even in the vicinity of the observed maximum length. The author remarked, however, that since the growth of most living organisms is logarithmic, results of this sort may indicate that it is unreasonable to postulate the various groups as age groups.

There are no great discrepancies in the growth estimates by Uno, Aikawa and Kato, Nakamura et al and Suda, and their results approach curve 5, Fig. 1, which indicates that albacore is a relative slow growing species. Deduced growth from size frequency analyses of Pacific albacore by Kawasaki and Aizawa (1955) also fit to this growth curve.

Partlo (1955) studied age and growth of albacore caught in waters adjacent to British Columbia. From vertebral rings he back calculated body length and tested his results by separating modal size groups occurring in commercial catches. The modal size groups closely agreed with those found in the Western Pacific, but were found to be one year younger. As the reason, Partlo suggests that the first ring measured in his study was not accepted as an annulus by the Japanese workers.

Brock (1943) analysed modal size groups of albacore caught during 1924 to 1928 off California and Oregon. In Californian waters the author found a more uniform relation in the yearly modal progression ("lagged difference") than in distance between modes of the same year. The growth rate was found to be somewhat more rapid than that for the Oregon albacore. According to Otsu (1960), the "lagged" modal values fall in nearly perfect agreement with growth estimates of 12 long-term recoveries of albacore tagged in Central and Western Pacific. Otsu found that the increase in length fitted to a Gompertz function (3.12) with parameters: a = 118 cm, b = 0.177, c = 1.43. This function is curvilinear contrary to the growth curves of albacore mentioned previously, and indicates a somewhat more rapid growth. However, the tagged fish were not measured individually and with so few data available this may lead to error in the growth estimates.

Le Gall (1950) examined length frequency of North East Atlantic albacore and separated four modal size groups. In a later work, Figueras (1957) calculated the growth of albacore from the same area by the method of back calculating body lengths from the rings on the vertebral faces. The modal lengths found by Le Gall correspond remarkably well to the mean length of the age groups II to V estimated by Figueras. Figueras found the one-year-old fish to be of the same size as those described by Partlo but deduced, as Otsu (1960), a somewhat more rapid growth rate (Fig. 1, curve 6).

4.4. Skipjack

Aikawa (1937b) and Aikawa and Kato (1938) estimated growth of skipjack on the basis of vertebral ring measurements, and found a linear growth. One-year-old fish measured on the average 25 cm, 6-year-old fish 65 cm.

Size composition analyses of Japanese skipjack catches have been published by several authors (Uda 1932, Uda and Tukusi 1934, Okamoto 1940, Kawasaki 1952). The investigators have mainly been occupied by problems concerning migration and subdivision of populations but have in general agreed with the findings of Aikawa and Kato.

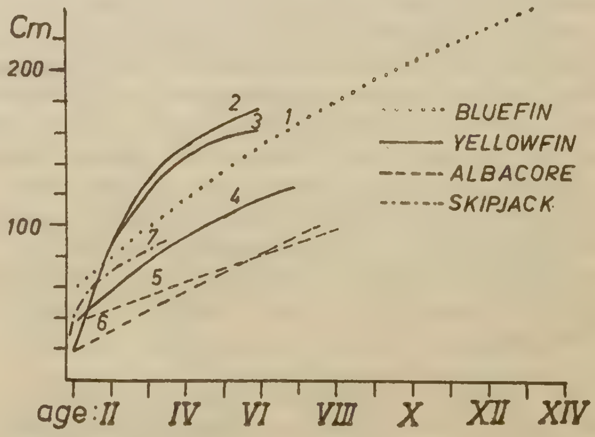

Fig. 1.

For explanation see text.

On the basis of length distribution of skipjack caught in the vicinity of Hawaii, Brock (1954) determined a growth curve which differs from that found by the Japanese workers, indicating a considerably more rapid growth of the species (Fig. 1, curve 7). This relatively rapid growth is substantiated by size frequency analyses and tagging experiments carried out in the Eastern Tropical Pacific (Schaefer 1961).

4.5 Bigeye Tuna

Nakamura et al (1953) investigated size frequencies of bigeye and found similar discrepancies in positions of modes as for the albacore. Predominant modes were centered at 85 to 88 cm, 121 to 124 cm and 149 to 152 cm for tuna caught in the period November 1948 to March 1949. From October 1949 to March 1950 the predominant modes were located at 93 to 96 cm and 137 to 140 cm.

Kamimura and Honma (1953) studied modal size groups of longline caught bigeye in the Pacific north of latitude 26°N and between longitudes 130°E and 165°W in five successive seasons from October to March 1948 to 1953. It was observed that the modes appeared at similar positions for the different areas in the same year but, as found by Nakamura et al (1953), they observed conspicuous discrepancies from year to year. The data indicate a two-year cycle in the position of the modes, which was assumed to be due to annual differences in the recruitment or annual differences in the migration pattern. In another work, Honma and Kamimura (1955) examined the size composition of young bigeye caught with pole-and-line. Aggregate data of the two works show modal lengths at 55, 75, 95, 115, 135, and 150 cm. Providing that the modal length groups represent year-classes, the growth rate is nearly constant within the size range concerned.

Iversen (1955) investigated weight frequency of bigeye landed at the Hawaiian fish market. He observed that dominant size groups have a period of two years, apparently the complement of the cycle in the Japanese North Pacific fishery, from which length data were available for comparison. Progressing modes indicated a yearly increase in weight up to 25 kg. None of the investigators has made any attempt to trace the growth curve.

5 RECRUITMENT AND REPRODUCTION

For fish species which spawn pelagically, as do the tuna, it is commonly assumed that the larval mortality rate is very high at the early stages. It is further realized that the recruitment is independent of the egg production within wide limits. Such a mechanism has been explained theoretically by assuming the larval mortality rate to increase linearly with the egg density, which may be due to limited quantities of food in the immediate environment (Ricker 1954, Beverton and Holt 1957). The most critical stage of survival may be when the yolk-sack is consumed and the fry become dependent on their own ability to obtain food (Sette 1943).

The age at which the tuna enter the different fisheries varies considerably with regard to localities and fishing gears. Though few investigators have paid attention to this particular question, this is evident from the size-frequency studies. Concerning the gears, live bait, trolling and purse-seine fisheries generally exploit the smallest and youngest part of the populations, while longlines preferably catch the oldest part. An exception is the Norwegian purse-seine fishery of bluefin, which is based upon the adult stock (tuna from 5 to about 15 years of age). Live bait, trolling and purse seine catch the tuna at the surface and the recruitment to the catchable stocks seems to take place when the fish are in their second year. Schaefer (1961) discussed this particular question regarding Eastern Pacific yellowfin and arrived at the conclusion that the year-classes were fully recruited at 1.5 years of age.

The longlines, which are used in the high-sea tuna fisheries, catch tuna in subsurface layers. The catches consist mainly of fish which have reached sexual maturity. The possibility that the difference in size between catches taken by the different gears may be due to simple gear selectivity has been mentioned. However, the most commonly accepted hypothesis is that the fish of the older age groups inhabit deeper waters and thus become more available to longlines than to the gears which operate in the surface. In all probability, the recruitment to the longline fisheries takes place at a relatively high age.

Variation in the amount of yearly recruitment to the catchable tuna stocks has been mentioned previously as a possible cause of the yearly alternating modal size groups occurring in longline caught albacore and bigeye tuna (Nakamura et al 1953). Suda (1954), who made a theoretical consideration of the mechanism of the alternate year cycle, regards the yearly variations in propagation as the most likely explanation of this phenomenon. A considerable variation in the strength of year-classes have been observed in Norwegian bluefin tuna catches (Hamre 1958). In the period 1957 to 1961, for instance, more than 50 percent of the total catch consisted of a definite modal size group, believed to be the 1950 year-class. It is assumed that the variable strength of the year-classes in Norwegian tuna catches is due to an annual variation in recruitment. However, variations in migration pattern may be partly responsible for this observation.

6 MORTALITY

6.1 Definitions

The mortality rate in a population is the proportion of individuals dying within a chosen time unit. In numerical terms, this may be expressed as follows:

$$a_t = \frac{N_0 - N_t}{N_0} \qquad (6.1)$$

$$e^{-Zt} = \frac{N_t}{N_0} \qquad (6.2)$$

where N_0 is the initial number of fish, N_t the number which have survived the time interval t. a_t is known as the total mortality rate. In an exploited fish population a_t consists of the fishing mortality rate m_t and mortality due to other causes, usually termed the natural mortality rate n_t. In practice these coefficients express the probability of death, and consequently:

$$a_t = m_t + n_t - m_t n_t \qquad (6.3)$$

In (6.2) the mortality is expressed as an exponential function, in which Z is known as the coefficient of instantaneous mortality rate. To this corresponds, in an exploited stock, an instantaneous fishing mortality coefficient F and an instantaneous natural mortality coefficient M:

$$Z = F + M \qquad (6.4)$$

As distinct from (6.3) the instantaneous measurements of mortality can be treated as independent variables.

The survival rate is the complement of the mortality rate:

$$S_t = 1 - a_t = \frac{N_t}{N_0} \qquad (6.5)$$

The relations between Z, a and S in terms of annual census (t = 1) are according to the equations (6.2), (6.5):

$$Z = \div \log_e S = \div \log_e (1-a) \qquad (6.6)$$

6.2 Estimates of Mortality Rate of Tunas

Mortality rates within a fish population can be derived from records of (a) size and age composition; (b) tagging experiments; and (c) catch and fishing effort in successive years. The literature describing methods of numerical treatments of the three categories of data is very extensive. A recent review of this literature has been given by Ricker (1958).

So far there is little knowledge of survival and mortality rate within the different tuna populations. Tauti (1940) has made attempts to calculate survival of bluefin, yellowfin and albacore caught in Japanese waters. For adult bluefin (3 years or more) he arrived at an annual survival rate of 0.57, for fish in the second year of life he found S = 0.23, and for the third S = 0.34. The basic data were size records of landings at the ports of Numatzu and Aburatsu in 1937, grouped to age according to the findings of Aikawa and Kato (1938). S was estimated from the abundance of successive age-groups employing the formula for cases of constant survival rate (Lea 1930, Jackson 1939):

$$S = \frac{N_{t+1} + N_{t+2} \ldots\ldots\ldots + N_{t+n}}{N_t + N_{t+1} \ldots\ldots\ldots + N_{t+(n-1)}} \qquad (6.7)$$

This formula combines series of estimates of the form (6.5). The abundance of age-groups were deduced from the amount of catch, disregarding fishing efforts.

In catch records of bluefin, caught on the Shigedera grounds from 1924 to 1932, the adult bluefin were grouped in three size categories, small (under 40 kg), medium (40 - 100 kg), and large (over 100 kg), by Kimura and Ishii (1933). Using the findings of Aikawa and Kato (1938), Tauti (1940) substituted age-groups in the three size groups and estimated the survival rate from differences in the abundance. With a constant survival rate and a constant recruitment, the number of fish in successive year-classes can be expressed by the figures N_o and S: N_o, SN_o, S^2N_o, etc.

If R is the ratio of abundance of younger fish to the older ones, and k the number of age-groups which constitute the younger part of the population, S can be calculated from the formula:

$$R = \frac{N_o + SN_o + \ldots\ldots\ldots + S^kN_o}{S^{k+1}N_o + S^{k+2}N_o + \ldots\ldots}$$

$$\sim (1+S+\ldots\ldots\ldots+S^k)\,\frac{S^{k+1}}{1 - S} \qquad (6.8)$$

Employing (6.8) for calculating S, Tauti found the average survival rate of adult bluefin on the Shigedera grounds to be 0.74. A similar technique was used to determine S of adult bluefin landed at the port of Kushiro in 1922 to 1932 (Kawana 1934), and for adult fish caught in offshore waters in 1937 to 1939. On the average, S = 0.68 and S = 0.84 were found for the two series of data respectively. From these findings Tauti concluded that the survival rate of Western Pacific bluefin had been about 0.30 for young and 0.75 for the adult fish. Assuming a constant natural mortality rate of fish older than one year, he deduced from the catch ratio between young and adult, a fishing mortality rate of 0.55 and 0.10 for young and adult bluefin respectively, with a natural mortality rate of about 0.20 (6.3).

Concerning Western Pacific yellowfin, Tauti studied survival rates on the basis of several sources of data, using the same methods as for bluefin. For the adults which had entered upon a migratory life, the author found a survival rate of 0.57. For the young yellowfin, living around islands and bays, he arrived at a survival rate of 0.75. By assuming that the natural mortality rate of yellowfin is similar to that of bluefin, the author calculated the fishing mortality rate to be 0.29 for adult and 0.06 for the young yellowfin.

On the basis of catch record of albacore compiled by the Japanese Tuna Canners Association in 1934 to 1937, Tauti converted size groups to age and calculated the survival rate. For the successive years he got the following values of S: 0.54, 0.84, 0.56 and 0.64 for 1937. The figures average 0.66. The variations in S were assumed to be due to variation in the age composition, caused by fluctuations in the behaviour or migration pattern.

In a later work, Tauti (1943) investigated the survival rate of skipjack in waters adjacent to the Japanese Islands. From the literature he concluded that after the skipjack have spent their juvenile period in the region of the South Sea Islands they make a migration northward along the Kuroshio in spring and early summer, returning to the southern waters in autumn. Consequently the catches from the South Sea area in late autumn provide the best basis for estimates of the survival rate. On the basis of catches taken on the Palaw fishing grounds, he found S = 0.54, using formulas similar to (6.8) for the calculation.

According to Schaefer (1961) the mortality rate of Eastern Pacific yellowfin has been estimated from the change with time in relative abundance of year-classes as they pass through the fishery using catch per unit of effort to compute the relative abundance. The estimates were derived from the catch curve. This method gives a better approach to the mortality rate than (6.7). The formula is obtained by taking the natural logarithm to (6.2):

$$\log_e N_t = \log_e N_o - Zt = \log_e N_o - (M+F)t \qquad (6.9)$$

Plotting natural logarithms of the abundance of a fully recruited year-class (N_t) against the age t, the points will approach a straight line. This line is known at the catch curve (Baranov 1918), the slope of which is equal to the coefficient of instantaneous mortality rate.

Assuming M to be constant, separate estimates for M and F may be obtained from (6.9) by comparing year-classes which have been subjected to different rates of exploitation. From catches of Eastern Pacific yellowfin in 1954 to 1959, the average estimate of Z was found to be 1.72, which corresponds to an annual mortality rate of 0.82 (6.6). The annual natural mortality rate n was believed to be about 0.55 (M = 0.80).

7 DISCUSSION AND CONCLUSIONS

The accuracy of the vital statistic estimates depends upon the validity of the methods employed in determining the age and on whether the available data are representative. With respect to the former, it is realized that the interpretations of marks in hard parts of tuna are questionable since no definite proof of an annual origin has been established. In the case of yellowfin and skipjack, which are mostly restricted to the tropical sea areas, it has been shown that the growth rate derived from ring measurements is considerably slower than that deduced from other methods including tagging experiments. On the basis of this observation, it seems fair to conclude that the rings used in determining the age of these species are formed more than once a year. With regard to yellowfin, this conclusion is substantiated by the two seasons of ring-formation found by Nose et al (1955). It may be noted that the considerably slower mortality rate of yellowfin found by Tauti (1940) than that calculated by Schaefer (1961) is partly due to the slow growth rate found by Aikawa and Kato (1938) and used in Tauti's calculations.

For albacore, Otsu and Uchida (1958, 1959) paid special attention to the methodological problems in determining the age of the fish by marks on scales and bones, and found several indications which threw doubt on the validity of the method. There is, however, a far lesser discrepancy in the growth rate of albacore deduced from different methods than was evident for yellowfin and skipjack. The discrepancy in growth rate deduced from tagging experiments (Otsu 1960), and investigations on vertebral rings (Partlo 1955, Figueras 1957) is small and may depend more on different numerical treatments of the data than on actual difference in growth. However, the higher growth rate found by Otsu indicates, as for the former species, that more than one ring may be laid down in a year.

With regard to bluefin, the investigators, working on the Atlantic stock, have arrived at similar results concerning the growth rate, whether they have based their studies on zone structure, size frequency analysis or data from tagging. Obviously the rings in hard parts of bluefin appear more distinct than in the species mentioned above and should consequently permit a more precise reading. Although there is also room for personal bias in counting rings of bluefin, especially for large fish, the data so far available point in the direction of an annual ring formation with regard to this tuna species.

It is generally assumed that seasonal fluctuations in the environmental conditions are the main causes of ring formation in the hard tissues of the fish. It is further realized that in temperate and cold waters, but not in the tropics, such variations are considerable. Since yellowfin and skipjack are restricted to the tropics, albacore is a more subtropic species, and bluefin live a great part of their life in temperate waters, it is reasonable that the age determinations by year rings vary with regard to the species as indicated above.

Several students have traced growth curves of tunas which approach straight lines. As the growth of animals is assumed to be logarithmic, the constant growth rate has been pointed to as evidence against the justification of the methods employed. Suda (1954), for instance, was inclined to regard it as unreasonable to postulate his finding of clear cut modal size groups of albacore as age-groups due to the equal distances between the modes. It is, however, very difficult to establish any reasonable interpretation of Suda's observations and other similar findings (Nakamura et al 1953, Le Gall 1950), without accepting the presence of age-groups.

The validity of the method of age determinations of tunas by size frequency analyses may also be questionable as the method postulates that the spawning takes place within a strictly limited season. The constant environmental conditions in the tropics may allow spawning throughout the whole year, and extensive spawning seasons of tropical tunas have been found by several authors. Yabuta and Yukinawa (1957) observed secondary size components occurring between the dominating modal size groups in Japanese yellowfin catches. The authors regard this to be caused either by selective sampling from the year-classes or from fish with different spawning periods. Hennemuth (1961) made a similar observation in the case of Eastern Pacific yellowfin. The findings of Brock (1943), that "lagged" differences in modal size groups of albacore were more uniform than distances between modes, point to a yearly variation in the spawning time. These circumstances may lead to errors in the growth estimates. In order to improve this technique in determining the age of tunas, work to obtain more knowledge of their spawning behavior is desirable.

The vital statistic estimates of tunas for determining the population structure may further be subject to several sources of error connected with the sampling procedure, both with regard to the available data as a sample of the catch and the catch as a sample of the population. For the former case the sources of error are strongly related to the practical circumstances which restrict the students and govern their choice of sampling program. These problems vary considerably with regard to different fisheries and localities. Such errors may be revealed by a statistical treatment of the sampling method in question (Hennemuth 1957). A far bigger and more obscure question is, however, the sources of error due to selectivity factors acting under the fishing operations. Differences in availability of fish of unequal size, either because of gear selectivity or due to subdivision of the stock, may result in discrepancies between the size structure of the catches and that of the whole population. These circumstances may lead to considerable errors in the estimates of all the vital statistics.

Methodological Paper No. 4

THE MATTER OF AVAILABILITY AND THE HARVEST OF TUNAS

By

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Abstract

Problems associated with fluctuations in availability and variations in vulnerability of the commercially important tunas are described; present knowledge concerning these fluctuations is reviewed; and suggestions are made for future research. Variations in availability are shown to be troublesome in determining optimum harvest and to affect fishing success. Explanations and examples are provided of current research practices concerning them which are: to describe and associate features of the oceanic circulation and distribution of properties with occurrence of tunas; to interpret variations therein; and to develop empirical relationships of predictive value. Consideration of the vulnerability of tunas to fishing gear is restricted to general features of their behavior and to the potential usefulness of behavior research. Discussion of future research dwells on the need for intensive studies of temporal variations in the environment; the coupling of oceanographic and meteorological research; comprehensive oceanographic surveys; and the progressive shift to studies of dynamic processes. Concern is registered that the research required is excessive relative to the importance of existing fisheries but this is more than mollified by man's growing demand for increased knowledge of the ocean.

THONS : DISPONIBILITE ET PRODUCTION

Résumé

La communication décrit les problèmes que posent les variations de la disponibilité et de la vulnérabilité des espèces de thons commercialement importantes, passe en revue les connaissances actuelles sur ces fluctuations, et présente des suggestions intéressant la recherche future. Les variations de la disponibilité compliquent la détermination du rendement optimal constant et compromettent les résultats de la pêche. A cet égard, l'auteur fournit des explications et des exemples des pratiques actuelles en matière de recherche: description des caractéristiques de la circulation océanique et de ses propriétés relativement à la présence de thons; interprétation des variations; établissement de rapports empiriques permettant de faire des prédictions. L'examen de la vulnérabilité des thons aux engins de pêche est limité aux caractéristiques générales de leur comportement et à l'utilité que peut présenter la recherche en matière de comportement. En examinant l'activité future dans le domaine de la recherche, l'auteur attire l'attention sur les points suivants: nécessité d'intensifier l'étude des variations chronologiques du milieu; association de la recherche dans le domaine de l'océanographie et dans celui de la météorologie; organisation d'enquêtes océanographiques approfondies; place de plus en plus importante accordée aux études des processue dynamiques. On s'est demandé si les travaux de recherche exigés ne sont pas excessifs par rapport à l'importance des pêches actuelles, mais cette objection ne résiste guère aux exigences croissantes en matière des connaissances océanographiques.

LA CUESTION DE LA DISPONIBILIDAD Y LA COSECHA DE ATUN

Extracto

Se estudian los problemas relacionados con las fluctuaciones de la disponibilidad y con las variaciones en la vulnerabilidad de los atunes de importancia comercial; se pasa revista a los conocimientos actuales sobre tales fluctuaciones y se formulan propuestas para investigaciones futuras. Se demuestra que las variaciones de la disponibilidad perturban la obtención de una cosecha óptima e influyen en el éxito de las actividades de pesca. Se proporcionan explicaciones y ejemplos de los actuales sistemas de investigación referente a las mismas consistentes en: describir y asociar características de la circulación oceánica y de la distribución de sus propiedades con la presencia de atún; interpretar las variaciones dentro de aquéllas; desarrollar relaciones empíricas de valor predictivo. El estudio de la vulnerabilidad de los atunes a los artes de pesca se limita a las características generales del comportamiento de aquéllos y a la utilidad potencial de las investigaciones sobre tal comportamiento. La discusión de las investigaciones futuras se basa en la necesidad de realizar estudios intensivos de las variaciones temporales del medio ambiente; la combinación de las investigaciones oceanográficas y meteorológicas; los reconocimientos oceanógraficos generales; y la orientación progresiva hacia los estudios de los procesos dinámicos. Se reconoce que la investigación que se considera necesaria es excesiva en relación con la importancia de las actuales pesquerías, pero esto queda contrarrestado con exceso por la creciente demanda por parte del hombre de un mayor conocimiento del océano.

1 INTRODUCTION

Year-to-year and season-to-season fluctuations that occur in the catches of many kinds of marine fishes are of concern to fishery scientists and the fishing industry alike. They complicate the task of determining the optimum harvest and they cause production costs to be higher than if the supply were uniform.

Determination of the optimum harvest of a fishery, usually considered to be the maximum sustainable yield, requires an understanding of the interrelationships among population size, fishing intensity, and average catch. Three principal elements operate to determine the catch: abundance of the species, its availability to capture, and amount of fishing. The means are at hand to measure changes in the amount of fishing effort and to account for its effects. Variations in availability and abundance present problems in biology and oceanography and are more difficult to identify and understand, much less measure. Availability, which is a matter of distribution and behavior, is suspected to vary widely for many of the tunas which range over vast regions of the ocean.

If fluctuations in availability and abundance cause problems in determining the optimum harvest by scientists, they are also frequently troublesome to fishermen. Variations in distribution and abundance are responsible for much time wasted in searching for fish and can even cause the complete failure of a fishery. Failure of the United States west coast albacore fishery from 1928 to 1938 almost certainly was an availability phenomenon. Effectiveness of fishing gear is dependent on the behavior of fish and, since behavior often varies with age and distribution, this is another aspect of availability which affects the catch.

Research to discover why tunas concentrate where they do, when they do, and to learn of other features of their behavior, is in its infancy but is receiving more and more support. The latter is fortunate because what little has been discovered demonstrates clearly that such research can make an important contribution to the strategy of fishing, the improvement of harvesting efficiency, and the basic problem of conservation.

The intention in preparing this background paper was to highlight present understanding concerning the availability of the commercially important tunas and to make suggestions concerning future research. The author was assisted in this task by his colleagues, Messrs. Glenn A. Flittner and James H. Johnson, who reviewed the manuscript and offered valuable suggestions.

2 THE PROBLEM

2.1 Definition of terms

Availability is not as well understood as some other terms used by fishery scientists. This may arise because quite different connotations are attached to it. Most frequent usage refers to the portion of the total population within the geographic range of the fishery. Another meaning refers to the behavior of the fish within the range of the fishery as this relates to capturing the fish. Marr (1951) and Ahlstrom (1959), among others, have discussed the terminology at length.

Ahlstrom's definitions are suitable for a discussion of tuna availability. He defined availability as the "portion (percentage) of the recruited population that is physically within the geographic range of the fishery during the fishing season," and removed the matter of behavior relative to the effectiveness of fishing gear. This special aspect of availability he called "vulnerability" and defined it as "accessability of the fish within the geographic range of the fishery to the efforts of fishing." The definitions imply measurement, but for the tunas at least, what is known so far about availability and vulnerability is qualitative rather than quantitative.

2.2 Availability

Changes in availability of fishes are a reflection of the response of a population to changes in its environment. Understanding these fluctuations, and other population fluctuations, for that matter, and measuring them, requires a fundamental knowledge of the interplay of pertinent atmospheric, oceanic, and biological processes. The chain of events which affects and controls the environment begins with the atmosphere. Changes in the atmospheric pressure field result in variations in wind stress. Variations in wind stress affect the surface circulation through changes in the velocity, depth and breadth and a multitude of other features of ocean currents. Currents affect the distribution of organisms at all trophic levels. Currents and wind determine the nature and strength of refertilization processes whereby cool nutrient-rich waters are brought from great depths to the surface. The replenishment of surface waters affects primary biological production which, in turn, affects secondary production at each trophic level up to the fishes, with varying lags in time and space.

Fishery scientists and oceanographers are far from understanding the interplay of atmospheric, oceanic and biological processes as they cause fluctuations in the availability and abundance of fishes and forecasting such fluctuations. The current practice is to concentrate on describing the oceanic circulation; to associate physical, chemical and biological parameters of the ocean with the occurrence of fishes; and to document and interpret changes in the distribution of the fishes in relation to changes in the properties measured and features described. The bulk of this activity, as far as the tunas are concerned, has taken place during the past ten or 15 years and has been concentrated in the Pacific Ocean. The result has been that the general surface circulation and distribution of properties have been much more thoroughly described than before and variations therein, among seasons and years, have begun to be appreciated.

During the course of this descriptive work, a few successful attempts have resulted in predicting where and when patterns associated with availability will occur. Admittedly, where ability to predict has been obtained, only partial understanding has been achieved. Nevertheless, the ability has had practical application and empirical relationships derived have become the basis of hypotheses to be investigated and tested.

The importance of fluctuations in availability, as they hinder understanding of the interrelationships of population size, fishing effort and average catch, and as they cause wide variations in total catch, varies among tuna fisheries. Availability can be a major factor when the fishery is carried out over only a portion of the migratory route of the species. Most fisheries for the so-called temperate tunas (albacore and bluefin) and many for the tropical skipjack are of this type and, as a result variations in availability appear, presently at least to be more important than variations in abundance in determining yields. Recorded failures and successes in the seasonal fisheries of the United States west coast and the Japanese Home Islands almost certainly have been availability phenomena because they have not occurred concurrently (Uda 1961a), even though the two fisheries operate on the same Pacific-wide population.

Variations in availability are neither as apparent nor of equal concern, either to scientists monitoring the dynamics of the population or to fishermen, in the important fisheries for the tropical yellowfin and bigeye tunas. This is because these fisheries take place at all seasons and their geographic extent coincides, more or less, with the distribution of the population.

The two situations are well illustrated in the companion tropical fisheries for yellowfin and skipjack in the eastern Pacific, about which more is known that any other tuna populations. For the yellowfin, all evidence points to closely allied geographic ranges for the population and the fishery, and scientists have arrived at an understanding of the average relationship among fishing intensity, population size and catch (Schaefer 1961a). Were there wide fluctuations in availability, or in other fishery-independent factors, the scientists concerned could hardly have reached their present understanding in the brief years that they have been studying the fishery. In contrast, the same understanding has not been obtained for skipjack. This population appears to be greatly affected by variations in fishery-independent factors, of which availability would seem to be a major one (Schaefer 1961a, Fig. 9; Sette 1960, Fig. 162). The skipjack situation appears to be like that of the seasonal albacore fisheries; the geographic range of the population is more extensive than the area in which the fishery is prosecuted.

2.3 Vulnerability

Vulnerability of fish to capture within the geographic range of a fishery depends on the effectiveness of the fishing gear employed relative to the behavior of the fish. Aside from economic considerations, the geographic range is dependent on the characteristics of the vessels engaged, notably their range and carrying capacity.

Tuna fishermen, especially those of the United States and Japan, have, over the years, effectively improved the efficiency of their gear and extended the range of their fishing activity. The Japanese have enjoyed considerable assistance from fishery laboratories in these pursuits. Today, fishing for tuna takes place over most of the world's tropical and subtropical seas. Few areas remain inaccessible to fishing vessels, so it is unlikely that future attention, with respect to vulnerability to capture, will be focused as heavily on exploratory fishing. Rather, emphasis probably will be to improve existing fishing methods and to develop new and more effective ones. Special attention is bound to be given to the tuna resources which are not now subject to exploitation because existing gear is ineffective, such as for the surface skipjack resources in vast areas of the tropics.

Scientists are expected to make important contributions to the improvement of fishing through behavior studies. Many believe that the elucidation of patterns of behavior can help make existing fishing methods more efficient and suggest more effective means of harvesting.

3 AVAILABILITY AND OCEANOGRAPHY

During the past 15 years or so, several broad investigations of the relationships between the tunas and their oceanic environment have been initiated in various parts of the Pacific Ocean. Schaefer (1961b) has summarized the important tuna oceanography programs of the central and eastern Pacific, and the activities of important Japanese laboratories in the western Pacific were described by the Fisheries Agency of Japan (1959). These investigations are providing the beginning of understanding of some relationships of tunas to their environment.

Studies of the broad geographical distribution of tuna catches from logbook records of fishing vessels by the Nankai Regional Fisheries Laboratory (1959) and the Inter-American Tropical Tuna Commission (Alverson 1960) have demonstrated clearly that tunas are not distributed evenly over the ocean but tend to concentrate in certain specific areas. Whereas, concentrations in these specific, but vast regions are remarkably consistent, there are notable variations from year to year and season to season in the locations of centers of good fishing within these broad regions. Enough has already been learned to identify some features of the environment which control distribution, at least in part. Also, in the course of this research, empirical relationships have been discovered which have predictive value.

3.1 Relations to sea-surface temperature

Much attention has centered on studies of distribution and availability of the tunas in relation to sea-surface temperature. Such analyses have proved attractive because surface temperature observations are readily available over vast areas of the ocean, both historically and on a continuing basis. The wealth of data is accumulated routinely by merchant and naval shipping and by fishing vessels.

Sea-surface temperature observations have been compiled to show the geographic limits of the various tunas and in attempts to define their temperature range for fishing. These studies have contributed much to our understanding of variations in availability of the tunas. Relating surface temperatures to distribution and fishing success has proved more definitive when studied regionally than world-wide. Squire (1962) has drawn attention to differences between the surface temperature ranges of several species found in the Gulf Stream in the Atlantic and the ranges of the same species in other regions as provided by Uda (1959 1960). Hester (1961a) pointed out that any attempt to postulate some particular optimum temperature for albacore would have to explain the difference of several degrees in water temperature existing between the California troll fishery and the Japanese pole-and-line fishery. Inoue (1961) has recorded that surface temperatures around the Japanese Home Islands during the summer albacore pole-

and-line fishery are different from those encountered in the winter longline fishery for albacore in the central north Pacific and that albacore taken in the latter region are dominantly from wider age groups. As another example of the latter, it is not logical to pool observations from the area of the eastern tropical Pacific with those from the central and western tropical Pacific to show distribution or optimum fishing conditions for yellowfin in relation to surface temperature. In the former, there is a surface fishery and, in the latter two regions, yellowfin of considerably larger size are caught on longlines from well below the surface where the water is usually several degrees cooler than at the surface.

At their lower temperature extremes, all species of tuna almost certainly respond directly to marked changes and temperature may be a factor in determining their occurrence at the warm end of the scale. There are examples of fluctuations in tuna availability which can be explained solely on the basis of temperature at the lower limits of their tolerance but situations which may be caused by high temperature are less clear. Tunas in waters of higher latitudes may well prefer particular temperatures within the surface layer but most researchers agree that surface temperature does not directly influence the distribution and availability in tropical waters except near the upper and lower limits of tolerance. Surface readings in either case, of course, can be indicative of other features and phenomena known to affect aggregation, and this matter will be discussed in the next section.

Examples from particular tropical and temperate tuna fisheries illustrate our present understanding of the effect of variations in sea-surface temperature on availability of the tunas and our existing capability with respect to prediction:

Off Baja California (Mexico) and California, tuna forage organisms are abundant at all seasons, yet yellowfin and skipjack only occur seasonally in commercial quantities. Their summer occurrence coincides with the northward movement of the 20° to 21°C isotherm and they disappear from the region with its retreat (Blackburn 1962; Schaefer 1961b). In 1955, which was a cold year in the eastern Pacific, the two species and the 21°C isotherm penetrated poleward to 26° to 27°N latitude; by contrast, the northern limit extended to between 32° and 30°N in the warm years of 1958 and 1959.

Schaefer (op cit) has pointed out that there is a striking relationship between the tropical tunas and surface temperature off the coast of Peru and northern Chile. Besides the seasonal changes in surface temperature to which yellowfin and skipjack respond, much as they do off Baja California, there also occur in some years widespread invasions of warm surface water along the coastal areas normally occupied by cold, upwelled water of the Peru Current. In years when the latter phenomenon takes place, the so-called "El Niño"years, the tropical tunas are more widely and sparsely distributed and occur much farther to the south.

Fluctuations in availability of skipjack, caused by avoidance of low surface temperatures, have long been known for the western Pacific (Takayama et al 1934; Uda 1938). Annual fluctuations in the area of origin of the Japanese Home Islands' summer skipjack catch and its magnitude as reflected by landings in three prefectures, Muyagi (northern Honshu), Shizuoka (central Honshu), and Kagoshima (Kyushu), are related directly to the poleward march of the 20° to 21°C isotherms. Robins (1952) has noted that the degree of southerly penetration of the skipjack seasonally along the east coast of Australia is related directly to temperature. Similarly, the northernmost limit of yellowin in the western Pacific in summer is typically about 35° N latitude but, in warm years, it extends past 40°N with a corresponding improvement in the availability of the species (Shapiro 1948).

Blackburn (1962) has suggested that unusually high temperatures may directly affect the availability of tropical tunas. Skipjack occur in varying abundance together with yellowfin along the coast of southern Mexico and Central America during the fourth quarter of the year (October-December). In the warm years of 1957 and 1958, skipjack were absent in the region of the thermal equator and yellowfin were appreciably less abundant. Examination of catch distribution charts (Alverson 1960) and surface temperature observations led Blackburn (op cit) to conclude that surface waters of 28°C are limiting for skipjack in the eastern Pacific and that yellowfin may also be affected by water this warm or warmer.

Albacore and bluefin range poleward annually as do the tropical species but their penetration into temperate waters is much more extensive. Seasonal fisheries supported by these migrations are subject to varying success in large part as a result of temperature-related variations in availability. This is hardly surprising. Sea-surface temperatures fluctuate widely in time and space at higher latitudes and these species occur in quantity only within particular temperature limits. Not only does temperature distribution affect the time and place in which these fisheries develop, their duration and the area encompassed, but it has also been found that there are optimum temperatures, within their range of tolerance, where these tunas are most available. Best fishing temperatures, for the albacore at least, vary with the age of the fish, time, area, and gear.

Surface temperature influences on seasonal fisheries for the temperate tunas are better known or, rather, better documented, for those off Japan and the North American west coast. The fact that temperature effects are similar suggests that they also are operative on temperate tunas in other regions of the world.

For the North American west coast, Johnson (1962a) has shown, using catch data of Clemens (1955), that the southern extent of best fishing for albacore is limited by about the 19°C isotherm, and Alverson (1961) has indicated that the Pacific northwest extension of the fishery is only successful when water is warmer than about 14°C. Johnson (1960) and Flittner (1961) have shown that the seasonal advance of the 15°C isotherm is accompanied by the northward distribution of albacore. Also, Hester (1961a) and Johnson (1962a, b) have demonstrated that the northern and southern extent and success of albacore fishing during the past 15 years were directly related to the seasonal march of the isotherms. The detailed temperature data for the area, for the period 1947-1958, were recently published by Johnson (1961).

Japanese scientists have demonstrated that the way in which the Home Islands' summer albacore fishery develops and the area it encompasses, is similarly controlled by seasonal warming (Inoue 1955, 1961; Van Campen 1960). Inoue has pointed out that albacore avoid surface waters colder than 16°C, which corresponds closely with the lower limit of 15°C given by Uda (1961a, Fig. 1).

The striking effect that variations in surface temperature have on bluefin fishing by California seiners was shown by Hester (1961a, Fig. 1). In 1952 and 1953 (two years of cold water temperatures), the area of most productive fishing lay in the vicinity of Punta Eugenia, Baja California, whereas, in the warm years of 1957 and 1958, it centered along the southern California coast, some 500 miles to the north.

The range of optimum water temperature for albacore fishing off Japan during the height of the summer pole-and-line fishery is variously given as between 18° and 24°C (Uda and Tokunaga 1937; Sasaki 1939). Sasaki stated that, over a number of years, 50 to 80 percent of the catch was taken at 20° to 21°C. Clemens (1961) has provided similar and more detailed information for the west coast United States albacore fishery by vessels operating from California ports. His information for the years 1954-1958 shows that about 70 percent of the fish has been caught between about 16° and 19°C, with best fishing between 16° and 18°C. Examination of catch-per-day's fishing and temperature showed similar results but he found that there was variation with gear used and age of the fish. Live-bait or pole-and-line fishing proved somewhat better in warmer water than troll fishing and the former gear tended to be selective for larger fish. Alverson (1961) has discussed the matter of optimum water temperature in relation to albacore catch and gear off Oregon and Washington. He concluded that, although total catch records indicate that the optimum temperature for trolling is about 14° and 16°C, catch-per-unit-effort data do not indicate as marked a decline in availability at higher and lower temperatures as might be interpreted from total catch.

The mechanisms responsible for albacore being most available at specific surface temperature within the range of availability are not yet clear. Some are probably directly related to temperature but temperature is also a reflection of other features of the circulation responsible for concentrating the fish, some possibilities of which are discussed in succeeding sections.

3.2 Relations to food supply

It is well known that the oceans are not uniformly productive. Large regions, particularly in the tropics, do not support fish in commercial quantities. Observations on the nature of occurrences of commercial concentrations of tunas have shown that they aggregate in particular locations. Beyond their direct response to surface temperature, and perhaps other factors not yet recognized, the important reference is their food supply. Therefore, much research attention is focused on understanding the systems of ocean currents and water masses, the distribution of their chemical and biological contents, and the physical processes which support biological production.

More is known about the occurrence of tunas, relative to circulation features and food supply, in subtropical and tropical waters than in temperate regions. Beyond the fact that more tuna oceanography has been conducted in the former, the nature of the tropical ocean may be contributing to quicker understanding of the mechanisms involved. It is a two-layer system which, over vast regions, is characteristically stable. The upper mixed layer is separated from a lower layer by a strong thermocline and is not subject to regular renewal as occurs seasonally at high latitudes. Tremendous areas are, therefore, depleted of nutrients and are biologically barren. In particular places, however, winds and currents cause replenishment of the upper layer through upwelling, vertical mixing, or thermal anticline situations. Such areas are rich in nutrients and biological productivity is high, beginning with the phytoplankton and culminating with large crops of tuna forage organisms and the tunas themselves.

Schaefer (1961b), in his summary of the status of tuna oceanography programs in the eastern and central tropical Pacific, for the past 10 years or so, where such studies have been concentrated, has pointed out features and mechanisms responsible for tuna food being abundant in some places and not others. Three prominent features are upwelling, vertical mixing and variations to the circulation caused by land masses or underwater protuberances.

Mechanisms of enrichment in the mid-Pacific and the correspondence of tuna concentration have received lucid portrayal by Sette (1955, 1956). His description of the equatorial divergence-convergence system south of Hawaii is an authoritative example of the effect of upwelling on the availability of tunas. The stress of the southeast trades, and Coriolis force north and south of the equator, causes divergence of the South Equatorial Current along the equator. This, in turn, brings nutrient-rich water to the surface which moves westward and away from the equator. North of the equator, the upwelled water apparently sinks, forming a zone of convergence between the center of upwelling and the southern edge of the Equatorial Countercurrent. As a result of unequal wind stress along the equator, upwelling is more intense in the vicinity of 120°W longitude but zooplankton and tuna forage organisms are more abundant to the west and north, at 150° and 160°W longitude, because of the time lag in biological production and the westerly drift of the South Equatorial Current. Variations in the strength, duration, and other features of the southeast trades apparently are responsible for fluctuations in the extent of upwelling with resulting variations in availability and abundance of the tropical tunas.

Schaefer (op cit) and Blackburn (1961, 1962) have pointed out that coastal upwelling is responsible for high productivity and the consequent aggregation of tunas in the eastern tropical Pacific along the coasts of Baja California and Peru. Coastal upwelling during the winter months may also contribute to the refertilization of the Gulf of Tehuantepec but Blackburn (op cit) found that the dominant feature of this region is vertical mixing associated with gales, cyclonic circulation, and a thermal anticline also known as a thermal dome.

Thermal anticlines are found where the thermocline is elevated to a position close to the sea surface well within the euphotic zone (Cromwell 1956, 1958). Typically, they move around and change shape, and the water composing them is renewed by inflow from below; reason for their formation is not yet understood. High productivity off Costa Rica and at other areas, such as in the Panama Bight and off the southern Mexican coast between Cape Corrientes and Manzanillo, appears to be the result of persistent thermal domes.

Fishing records show that the tunas are more abundant in the vicinity of offshore islands and seamounts than in other adjacent regions. There is evidence that these protuberances affect the flow of currents and otherwise cause vertical mixing which results in enrichment of the euphotic zone. Sette (1955) was among the first to make reference to the part of islands in modifying the circulation and causing enrichment of the euphotic zone. He reported that perturbations within the North Equatorial Current as it passes through the Hawaiian Islands results in vertical mixing, as evidenced by large-scale and semi-permanent eddies downstream, and that concentrations of skipjack are associated with the complex system of eddies. Bennett and Schaefer (1960) discussed the effect on the surface circulation of the Revilla Gigedo Islands and Shimada Bank in the eastern Pacific and have shown that these features modify to some extent the distribution of physical and chemical properties and that eddying and upwelling occur downstream, as hypothesized by Uda and Ishino (1958). Although their study indicated some increase in productivity (C^{14} uptake) and surface chlorophyll near Clarion Island and Shimada Bank, zooplankton volumes were scarcely higher. They suggested that there is the possibility that benthic forms, which are herbivorous or detritus feeders, may contribute greatly to the food of tunas in such places.

Tunas tend to be abundant in the vicinity of fronts, places of surface temperature discontinuities, which mark boundaries between water masses or water types.[1] Fronts are large-scale features in the former case and small-scale in the latter. In either case, at such places, there is convergence which results in the accumulation of plankton and, in turn, larger organisms and the predatory fishes. Large-scale fronts have been discussed by Uda (1961b) among others, who has reported that albacore concentrate in eddies along the Oyashio-Kuroshio boundary, and Brown and Sherman (1961) have noted the association of skipjack with boundaries between water types around the Hawaiian Islands.

3.3 Relations to other factors

Research programs have suggested other factors and features related to oceanic circulation besides surface temperature and food supply that affect the distribution and availability of the tunas. The way in which they operate is not yet understood or, at best, is speculative. One such feature is worthy of mention. This is the association of tunas with water masses. Recent papers on this subject were those of Yamanaka and Anraku (1961) and Inoue (1961) which reported on the distribution of the important tunas in the north and south Pacific, west of 160°W longitude, in relation to water masses and water types, and those of Brown and Sherman (1961) and Seckel and Austin (1961) dealing with skipjack in the vicinity of the Hawaiian Islands.

Yamanaka and Anraku (op cit) were able to show that seasonal variation in the distribution of water masses and sub-types in the western Pacific, as described by temperature-chlorinity curves for the upper 200 m, were accompanied by similar variations in the distribution of several species of tunas. Research in the Hawaiian Islands has indicated that the skipjack is associated with the water of the California Current extension. The species occurs in commercial abundance seasonally when the islands are bathed by this water. No appreciable seasonal variation in food supply is associated with these variations in distribution, or is yet apparent.

3.4 Prediction

An important objective of oceanographic studies in relation to the availability of the tunas is to forecast where and when tunas will be available to commercial fishermen and in what quantities. Studies have not yet progressed to the extent necessary to attain fully this objective, nor are they likely to until there are better means, in terms of synopticity and continuity, of collecting data concerning the environment, and, in most cases, the catches. However, at the present time, techniques based on empirical relationships are being developed and some are in use to predict major shifts in distribution associated with broad-scale changes in the oceanic circulation. Since studies of small-scale features of the environment in relation to the localized aggregation and dispersal of the tunas have only begun, advances toward prognostication have been even less in this area.

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[1] Seckel (1962) has distinguished "water mass" from "water type." He considered that the latter is under the direct influence of physical processes taking place at the sea surface, whereas the former is not.

Because more is known about the distribution of the tunas in relation to sea-surface temperature, it is not surprising that prediction techniques, developed and so far in use, have been based on temperature. It is not surprising, either, that, in general, it is easier to predict the distribution of the temperate tunas than the tropical species.

Johnson (1962b) has investigated sea-surface temperatures and landings of albacore in Oregon and Washington and found that, in years of above normal temperatures, landings were significantly greater than in years of below normal temperatures. Whereas warm water did not insure a good fishery, widespread cold water apparently was detrimental to the success of the fishery. His study shows that, if the sea-surface temperature anomaly off the coasts of Oregon and Washington is large in June, it is possible to predict whether or not sea temperatures will be favorable for albacore at the normal commencement of the fishery in July.

Hester (1961a) has found that the general regions of best fishing, and total catch within prescribed confidence limits, for albacore and bluefin during the summer in waters off southern California and Baja California, can be forecast on the basis of the average sea-surface temperatures at two southern California shore stations during winter. Similarly, Inoue (1961) has discovered that the location and success of the summer pole-and-line albacore fishery off the mainland of Japan can be predicted with considerable accuracy from sea-surface temperature information obtained during the previous winter from the regions of the central north Pacific winter albacore longline fishery.

With reference to the association of skipjack with water of the California Current extension in the Hawaiian Islands, a technique has been developed using surface water temperature observations from an island shore station to predict the availability of this species to the seasonal fishery, despite the fact that surface temperature in the region of the fishing is at all times of the year above the minimum for commercial abundance (U.S. Bureau of Commercial Fisheries 1961; Brown and Sherman 1961). The procedure used is related to the time of displacement of the extension of the Kuroshio Current, which flows through the island chain in winter, by the northerly movement of the California Current extension in spring. The time of change occurs between early February and late March and is reflected by a reverse from cooling to warming. The time within this period that the change occurs is related to the total catch of skipjack landed during the subsequent summer.

The examples of prediction cited are concerned with broad-scale variations in availability as reflected by changes in distribution and have been possible because large-scale sea temperature anomalies usually persist for several months. The techniques employed have application to other tuna fisheries, especially to seasonal fisheries. Their refinement can be expected as studies of the underlying causes of temperature anomalies and variations in other features of the oceanic circulation progress and as more attention is given to understanding the effect of the atmospheric circulation on the ocean.

With respect to the localized aggregation and dispersal of the tunas, prediction is still a matter of the future. However, the sea-surface temperature charts routinely issued for regions of the eastern and western Pacific Ocean by the U.S. Bureau of Commercial Fisheries at its Biological Laboratory, San Diego and the Japan Meteorological Agency, respectively, are of assistance to commercial fishermen in locating regions of optimum water temperature for fishing and for anticipating the movement and distribution of the tunas at the extremes of their range.

4 VULNERABILITY AND BEHAVIOR

Investigations of behavioral mechanisms of the tunas to understand and improve the effectiveness of fishing methods are recent in origin and few in number. The first such investigation began in 1957 when the U.S. Bureau of Commercial Fisheries, at its Biological Laboratory, Honolulu embarked on a program of study of the behavior of skipjack in the central Pacific. More recently, the Bureau initiated similar studies on the tunas of the eastern Pacific at its newly established San Diego Biological Laboratory. Before 1957, what little was known about tuna behavior had come from fishermen's observations and those recorded by individual scientists engaged in other endeavors.

Whereas the ingenuity of fishermen guarantees that fishing methods for the tunas will continue to improve, many scientists and fishermen are convinced that improvement could be accelerated if more were known about the behavior of these fishes, particularly about their feeding responses, schooling, association with other animals, and reactions to local physical features. It was this conviction that motivated the research begun at Honolulu and San Diego.

Any discussion of the behavior of the tunas relative to their vulnerability is certain to infringe on two other main agenda items scheduled for this meeting: (5) Physiology and Behavior, and (6) Fishing Methods. Since background papers have been prepared on these subjects, it is appropriate to confine this discussion to a few general features of the behavior of these fishes which affect their vulnerability and not dwell on what is known about the mechanisms responsible.

4.1 Relations to oceanographic features

Limitations and advantages of different fishing methods for the tunas are, in general, related to the distribution and behavior of the several species. We have seen that distribution is controlled by the oceanic circulation. In some respects, apparently, so is behavior. So little is known about the latter, however, that there are few examples to cite without being too speculative.

With respect to distribution, the live-bait fishing method is not effective where tuna fishing takes place far from where small bait fishes can be caught in quantity. Similarly, small vessels, no matter what gear is used, cannot fish far from land unless they operate from a mother ship. Beyond these special limitations and economic factors, of course, the advantages and disadvantages of the live-bait method and small boats are related largely to the behavior of the fish. As far as the other major fishing, purse-seining, longlining, and trolling, are concerned, the matter of behavior also appears to be the overriding factor in controlling their effectiveness.

One dominant behavioral characteristic of the tunas is that they live in the upper mixed layer of the open ocean. Differences in the penetration by the several species seem to be directly responsible for differences in the vulnerability of particular species to different gear.

In the tropics, purse-seine and live-bait methods are notably more successful along the eastern margin of the ocean where the mixed layer is shallow. In the eastern tropical Pacific, the thermocline is 20 to 70 m deep, depending on time and location. By contrast, longline fishing is the only method presently available which has proved successful for catching yellowfin and bigeye tunas in the tropics where the mixed layer is deeper (frequently well over 100 m), as in the central and western Pacific. These fishes apparently penetrate the entire range of the mixed layer. The wide-ranging skipjack must behave differently, though, and remain close to the surface whether the mixed layer be shallow or deep. Sightings of surface schools and the fact that longline gear is not effective for this species suggest this to be the case.

How variation in the thermocline depth within localized regions affects the vulnerability of tuna to particular gear is only now under investigation. Hester (1961b) describes some work begun by the U.S. Bureau of Commercial Fisheries at San Diego to determine the effective fishing depth of purse-seines and whether the thermocline depth and gradient affect the success of sets. This study has not progressed far enough to answer these questions but it has revealed that tunas will, under certain circumstances, enter the thermocline to escape capture by a seine.

There is great variation in the success of purse-seine sets for bluefin tuna. Purse-seining for albacore has not yet proved practical. In both circumstances, seining operations encounter pronounced thermocline variability over short distances and often at depths greater than those in the tropical regions where purse-seining is commonly practiced.

Whether the depth of the mixed layer is entirely or partly responsible for this difficulty or whether other behavioral characteristics pertaining to schooling are the cause requires investigation.

The way in which fishermen construct longline gear and the depth at which hooks are placed differ with species, locality and season. It may be that thermocline depth and corresponding responses of the several tunas require these modifications.

Murphy (1959) has reported that the numbers of albacore taken by gillnetting and surface trolling are markedly affected by the transparency of the water. Observations assembled from fishing cruises between Hawaii and the Aleutians and off the west coast of the United States showed that trolling efficiency was significantly better in clear water than in turbid water. The fact that live-bait fishing involves visual responses, as does trolling, may be one reason that purse-seiners have been, on the average, notably more effective than vessels employing the live-bait method in such areas as the Gulf of California where the water is more turbid. Catch records published by Alverson (1960) suggested this possibility even before recent improvements in seining techniques occurred.

4.2 Relations to behavioral characteristics

At the present stage of knowledge, discussion of behavioral characteristics of commercial fishes centers inevitably on what they do that makes them difficult to capture. Not much is known yet about why they do the things that they do.

Live-bait fishermen encounter all types of schools; likewise do albacore jig-boat fishermen and purse-seine fishermen. Some schools bite well, others bite poorly, and still others do not bite at all. Some schools are too scattered or move too fast to catch with either a purse-seine or live-bait. In certain areas, purse-seiners find that some schools are accompanied by so many porpoises as to make fishing operations extremely difficult. Since fishermen usually do not fish at night, schools located the afternoon before are often lost by morning. Do these schools maintain themselves at night? Can they be followed if they do? If fish are biting well at nightfall, can they be expected to bite the next morning? When can non-biting or non-feeding schools be expected to become feeding schools? When are scattered schools likely to become compact schools? These are only a few of the problems affecting vulnerability to fishing gear and only a few of the questions that need to be answered to assist fishermen in modifying their operational techniques and to suggest improvements to their gear. There are many others but we will leave this subject for further elucidation and for discussion of what is known about the behavioral mechanisms involved by those contributing to the two sessions previously noted.

5 FUTURE RESEARCH

In the span of 15 years, much progress has been made in our basic understanding of the scheme of things by which the atmosphere, the ocean and the biosphere are interrelated and how the interplay determines the distribution pattern of the tunas. Nearly all of the research effort has taken place in the Pacific Ocean. It has come about through broad surveys of the near-surface oceanic circulation and the distribution of physical, chemical and biological properties. It has been aided by constructing simplified descriptions of the atmospheric circulation considered to have major effect on the ocean circulation, and by averaging environmental and tuna catch data for broad regions over periods of months and even years.

So far, the research has provided a fairly adequate picture of the average distribution of the tunas in relation to general features of the oceanic circulation and the distribution of various properties. The results have not yet had any great impact as far as measuring and predicting fluctuations in availability and abundance of the tunas because temporal variations on both large and small scales have only begun to be studied and these studies have been confined largely to the examination of sea-surface temperature anomalies in temperate regions. Also, detailed studies of small-scale features of the circulation which appear to be important in the aggregation and dispersal of the tunas have only received casual attention. It is the study of temporal variations and small-scale features of the circulation which must now receive more attention if we are to understand, forecast, and eventually measure fluctuations in availability and abundance of the tunas.

5.1 Temporal variations

Much needs to be done in the study of temporal variations in the oceanic climate and corresponding changes in the distribution of the tunas. Perhaps the most urgent requirement is a better means of obtaining observations of environmental parameters and, in the case of most tuna fisheries, more detailed tuna catch and effort statistics, to better understand long-term and short-term variations.

Reliance on research ships for observations necessary to monitor temporal variations in the ocean is not satisfactory. It is not possible for a few research vessels to cover vast areas in a synoptic and continuous fashion; both features are essential. In instances where continuous observations have been possible, such as those at a station in the Hawaiian Islands for temperature and salinity (Brown and Sherman 1961), and where sea-surface temperatures have been available synoptically and continuously from merchant ships, as off the west coast of the United States, for example (Johnson 1962b), a great deal has been learned about temporal changes in the environment. At present, unfortunately, it is only possible to obtain synoptic time-series data of a few parameters at the sea surface from merchant ships and fishing craft. Few island and shore stations are in the right place, sufficiently widespread, or far enough offshore to provide adequate coverage. The cost that would be involved to obtain the observations required in both time and space would be prohibitive from research vessels. There is an urgent need for anchored stations at selected places which are capable of recording observations of as many parameters as possible at the sea surface and at intervals within the mixed layer and the thermocline.

The need for time-series data has been recognized by scientists other than those engaged in tuna oceanography. At the present time in the United States, considerable effort is being put forth by various groups to develop an inexpensive anchored unmanned buoy or data collecting device which will operate unattended for several months at a time and will store or transmit weather and oceanographic observations. The principal hindrance to its development has been the design of a satisfactory anchoring system. Instruments for recording some physical parameters are already available; attention is being given to sensors for other properties, including biological.

Operation of networks of unmanned data-collecting devices would make possible rapid advances in the study of temporal variations. O. E. Sette recently expressed the opinion (and many others will agree) that suitable monitoring systems alone, added to present research efforts, might well provide empirical understanding of some major problems concerning secular changes in the environment which give rise to major changes in the productivity of our fisheries.

Since the atmosphere and ocean are dynamic fluid systems affecting each other to a substantial degree, oceanographic investigations of temporal changes, particularly those of large scale, need to be coupled with meteorological studies. It is useful to draw attention to some of the work in this area to emphasize that more effort would be worthwhile. The U.S. Bureau of Commercial Fisheries Biological Laboratory at Stanford, California in 1956 began research into the relation of ocean-wide pulses to long-term weather patterns over the Pacific Ocean. The research has brought to light data pertaining to ocean changes, which until now, have been neglected (Sette 1960). The Inter-American Tropical Tuna Commission recently supported, with encouraging results, an investigation of the meteorological control over the periodic occurrence of the "El Nino" condition off the northwest coast of South America (Bjerknes 1961). Uda (1960) has reported a reciprocal relationship between sea-surface temperatures in the regions of the seasonal albacore fisheries of the western and eastern Pacific. Roden and Reid (1961) have found some agreement between anomalous pressures over the Pacific and anomalous sea-surface temperatures. Investigations of this type are needed to hasten learning about the underlying causes of gross variations in ocean features.

5.2 Oceanographic surveys

The operation of networks of unmanned data-collecting devices most certainly will not eliminate the need for observations from oceanographic vessels. An urgent need remains for gross surveys to map basic biological properties such as productivity and standing crops as well as physical and chemical parameters in each of the major tuna resource areas. These can be accomplished satisfactorily only from moving platforms. In addition, there are numerous special research problems dealing with special features and processes in the ocean that require the use of properly equipped research vessels.

Although much attention has been devoted to gross surveys of such tuna resource areas as the eastern and central tropical Pacific, these surveys have been too fragmentary and discontinuous in time and space. In such regions, available pictures of the oceanic circulation, its processes and special features, and the consequent distribution of the tunas are grossly "average." They have been drawn by assembling and analyzing data taken by one- and two-ship expeditions over periods of several years. These "maps" now need to be drawn in more detail to reflect seasonal variations in a synoptic fashion. This implies that more research vessels must be engaged in future surveys so that the observations and the geographic scope may be much more comprehensive. A detailed outline of these requirements for the eastern tropical Pacific Ocean is provided in a 1961 report of the Eastern Pacific Oceanic Conference (EPOC). Those for other areas are similar.

5.3 Investigation of special features and processes

There is little disagreement that semi-synoptic surveys and monitoring of the ocean environment must occupy the major share of the research effort in most ocean regions for some time yet to advance our understanding of fluctuations in distribution, availability and abundance of the tunas and other living resources of the sea. Although these activities alone will not furnish complete understanding of the physical, chemical and biological regime, they can provide understanding of some major problems and they will reveal features and processes requiring detailed and long-term study both at sea and in the laboratory.

Whereas the time is not yet ripe in most regions to shift emphasis from charting and monitoring distribution of properties to the study of dynamic processes which produce the distributions and of the principles which govern them, the present state of knowledge makes it possible to suggest a number of special studies which may well go hand in hand with the survey work. Attention is already being given to a few, such as coastal upwelling; the local influence of seamounts, banks and isolated islands on the physical, chemical and biological regimes; physical, chemical and biological phenomena in relation to oceanic fronts and interfaces as they directly or indirectly cause the aggreation of fish; formation, persistence and structure of thermal anticlines and their effect on the overall circulation. A host of additional special studies are suggested in the EPOC report (1961) but their relative importance cannot be determined until the survey work is further advanced.

5.4 Behavioral investigations

Whereas additional oceanographic research is required to advance the understanding of fluctuations in availability of the tunas, there is a companion need for support of behavior studies, now in their infancy, for these investigations are expected to provide useful information in developing and improving fishing gear. We will defer making suggestions as to the direction behavior studies may take to the participants of the other two sections of the meeting previously mentioned.

5.5 Some special considerations

What has been suggested in the way of future research is a vast undertaking; the effort is many-fold greater than that now expended. The results would contribute equally to solving other problems concerning the tunas far broader than matters of availability and vulnerability and they would have tremendously wide application in advancing knowledge about other fishery resources. However, one cannot help but be concerned, as was Sette (1961), that the effort required may be quite out of line with the importance of existing commercial fisheries. Sette did go on to point out, though, that fluctuations of the ocean and its living resources are now of concern and importance far beyond present interests in fisheries, as did EPOC (1961) in its specific justifications for a comprehensive program of study of the eastern tropical Pacific Ocean. The increasing complexity of our civilization and the urgent problem of the world's rapidly increasing population both demand increased knowledge about the ocean and its resources.

The press for protein food in the world is great and will become even greater. The land will not supply this need but the ocean is known to have living resources far in excess of the few efficient high-seas fisheries such as the tunas. Harvest of these resources, however, awaits technological know-how which is dependent on more knowledge of the ocean and its resources. Modern meteorology requires better understanding of the interplay between ocean and atmosphere, for air-sea processes are of critical importance to extended weather forecasting and possible future weather control.

It would seem that fishery scientists and oceanographers can expect with reasonable certainty that increased support for oceanographic research, so vital to the advance of their endeavors and the interests of the industries they serve, will not depend solely on their requests but also will stem from the need for information for other important activities of mankind. Furthermore, the need for intensifying ocean research transgresses national interests. All nations should look forward to the pooling of research results and the integration of work at sea to advance the studies more rapidly.

Methodological Paper No. 5

TUNA BEHAVIOR AND PHYSIOLOGY, A REVIEW

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Abstract

Published data on tuna behavior and to a lesser extent tuna physiology are reviewed. Feeding behavior and schooling behavior are covered more intensely. Data relevant to tuna behavior have been collected primarily by indirect methods, such as examination of stomach contents, distributions of tuna on longlines, etc. The use of sonar is also being expanded. Most studies of tuna behavior require direct observations of the behaving animal. Methods of making direct observations at sea from airplanes, or through underwater portholes in ships have been developed, as have methods of observing tuna directly in captivity. Studies on mackerel also provide information useful in understanding tuna behavior. In the author's opinion ethological study of tuna in captivity will provide the most rapid rate of increase in the understanding of tuna behavior.

COMPORTEMENT ET PHYSIOLOGIE DU THON - REVUE DE NOS CONNAISSANCES

Résumé

Cet article passe en revue les données jusque là publiées concernant le comportement du thon et, à un degré moindre, la physiologie du thon. Il couvre plus largement le comportement de nutrition et le comportement de déplacement en bancs. Les données concernant le comportement du thon ont été réunies d'abord par des méthodes indirectes, telles que l'examen du contenu de l'estomac, la distribution des thons capturés aux longues lignes, etc. L'emploi du sonar s'est également étendu.

La plupart des études sur le comportement du thon demandent des observations directes sur l'animal dans son milieu naturel. Des méthodes d'observations directes à la mer depuis des avions ou par des hublots sous-marins à bord de navires ont été mises au points, et aussi des méthodes d'observations directes en captivité. Les études sur le maquereau ont également fourni des renseignements utiles pour la compréhension du comportement du thon. L'auteur estime personnellement que l'étude éthologique du thon en captivité devrait apporter la contribution la plus importante au progrès rapide de notre connaissance du comportement du thon.

COMPORTAMIENTO Y FISIOLOGIA DEL ATUN: UNA RESENA

Extracto

Se reseñan los datos publicados respecto al comportamiento y, en menor grado, a la fisiología del atún. Se tratan con más detalle el comportamiento durante la alimentación y la agrupación. Los datos relacionados con el comportamiento del atún se han obtenido principalmente por métodos indirectos como el examen del contenido del estómago, distribución en los palangres atuneros, etc.; el sonar es objeto de empleo creciente. Casi todos los estudios del comportamiento del atún exigen observaciones directas del animal y para ello se recurre al aeroplano ó a los portillos sumergidos en barcos; también se han hecho observaciones directas en acuarios. Los estudios de la caballa facilitan datos de utilidad en la comprensión del comportamiento del atún. A juicio del autor, el estudio etológico del atún en el cautiverio dará las mayores facilidades para comprender su comportamiento.

1 INTRODUCTION

Behavior as defined by Tinbergen (1951) is the "total movements of the intact animal," and the scientific study of these movements is known as ethology. The theoretical background of ethology, especially as it concerns fish or fisheries biology has been recently reviewed by Baerends (1957), Hoar (1958), and Kesteven (1960). A thorough aquaintance with these fundamentals is essential to the fishery biologist studying tuna behavior.

The purpose of the present paper is to review the published data on tuna behavior and tuna physiology, to point out the methods used to collect such data, and to make suggestions for future work.

Since more information is available on behavior than on physiology, tuna physiology is considered only briefly. The greatest concentration of published information on tuna behavior is concerned with feeding behavior and schooling behavior. Studies with mackerel are used to supplement those on tuna where appropriate.

2 FEEDING BEHAVIOR

2.1 Methods of feeding

Scombrid fishes feed primarily on fish, squid, and zooplankton. An individual fish is capable of finding, catching, and ingesting a cosmopolitan collection of prey, differing greatly in shape, mobility, color, and size (Yuen, 1959; Tester and Nakamura, 1957). This ability results in part from great swimming power, from morphological adaptations present in the feeding apparatus, and apparently from a tendency to behave differently towards different species or types of prey.

Scombrids actively pursue their prey and swallow them intact (Suyehiro, 1942). Their teeth are poorly developed, and prey are not mortally wounded or dismembered before being ingested, although large prey are bitten on the trunk before being swallowed head first (Nakamura, H., 1949). All species except the wahoo, Acanthocybium solandri, have long gill rakers projecting forward from the first gill arch. The rakers presumably prevent the loss of smaller prey through the branchial clefts (Kishinouye, 1923).

Atlantic mackerel, Scomber scombrus, make individual attacks on relatively large sized food objects (Sette, 1950). In this situation the fish no longer orient parallel to each other and schooling is disrupted. Similar disruptions of schooling behavior during feeding have been observed in skipjack, Euthynnus pelamis (=Katsuwonus pelamis) (Nakamura, E., in press; Strasburg and Yuen, 1960a), little tunny, Euthynnus yaito (Tester et al., 1955), and Japanese mackerel, Scomber japonicus (=Pneumatophorus japonicus japonicus) (Hotta, 1960). When feeding on small food particles rather than large ones, Atlantic mackerel do not disrupt their schooling behavior, but instead form dense schools, open their mouths wide, and extend their operculums (Sette, 1950). It is not known whether this latter type of behavior occurs among tuna. Still another reaction to prey was observed by Hiatt and Brock (1948), who reported that little tunny herded prey. In contrast to this apparent cooperation, Allen (1920) observed that a Japanese mackerel, Scomber japonicus, dashing through the water with a 7.5-cm sardine protruding from both sides of its mouth, was chased by its companions, which grasped at the protruding ends of the sardine and eventually tore the sardine apart.

One very noticeable feeding behavior characteristic of skipjack is a sudden change in coloration from the horizontally striped pattern to one of alternating dark and light vertical bars (Kishinouye, 1923; Strasburg and Yuen, 1960a.; Strasburg and Marr, 1961). This change occurs when skipjack respond to food stimuli, and food stimuli do not release this color change in sated skipjack (Nakamura, E., in press). Transient vertical bars are also visible in photographs of Australian southern bluefin tuna, Thunnus thynnus maccoyii (Serventy, 1956), Chilean bonito, Sarda chiliensis (=Sarda lineolata), and Mexican bonito, Sarda velox (Walford, 1937). These specimens were photographed immediately after they were captured on baited hooks, but no experiments have been conducted to determine whether the color pattern was initiated by food stimuli. It is interesting to speculate that color, changes such as those described for skipjack are social releasers of biological significance to the species.

2.2 Food stimuli

Both visual stimuli and invisible chemical extracts of tuna food (smell or taste) release feeding behavior of tuna. Among the visual stimuli, brightness, size, and movement seem to influence the intensity of the feeding response. Light colored or shiny objects resulted in a greater feeding response than dark or dull objects (Hsiao and Tester, 1955; Shomura, 1955; and Tester et al., 1954) presumably because brighter objects were more visible. Increased visibility was also believed to account for higher catch rates of albacore, Thunnus alalunga (-Germo alalunga), with surface trolling lures in waters which were less turbid (Murphy, 1959). Nakamura, E. (in press) observed that partly satiated skipjack responded to small food objects, but not to larger food stimuli. Moving (live) anchovies, Stolephorus purpureus, are more effective as a food stimulus for skipjack at sea than are non-moving (dead) anchovies (Strasburg and Yuen, 1960a.;Yuen, in press).

Invisible chemical extracts of squid, shrimp, and a variety of fish released a feeding response in captive little tunny (Tester et al., 1954, 1955). The extent to which the extracts released feeding behavior was in part influenced by the previous feeding history of the fish. For example, if little tunny were fed shrimp, squid, or tuna flesh, the squid extracts released the most intense feeding responses in the fish which had been fed on squid for the previous week. The same was true of the response to skipjack extracts, among fish fed on skipjack, but was not true for the response to shrimp extracts. The response is not entirely a result of conditioning to the food provided to little tunny in captivity. Those fed squid and baitfish responded to skipjack extracts even though they had never been fed skipjack while in captivity.

According to the principle of heterogenous summation, if an object is characterized by more than one releasing stimulus, i.e. brightness, shape, taste or odor, movement, etc., the presentation of more than one of these stimuli at one time results in a more intense response by the animal. Hsiao and Tester (1955) demonstrated heterogenous summation of food stimuli by little tunny. For example, when neither visual nor chemical stimuli were presented, little tunny remained in the test area 12 percent of the time, when visual food stimuli alone were presented this increased to 24.5 percent, and when both visual and chemical food stimuli were presented this again increased to 29.5 percent. Likewise the number of feeding passes at the visual food stimuli (artificial lures) increased from 14 to 40 passes for a 15-minute period when chemical extracts were added. These results are from experiments with captive tuna, and attempts to increase the response of skipjack to artificial lures on pole-and-line fishing boats at sea by using chemical extracts have been inconclusive or unsuccessful (Tester et al., 1954).

Water sprays from pole-and-line fishing boats onto the surface of the sea increased the biting response of skipjack at sea (Strasburg and Yuen, 1960a.;Yuen, in press). It is not known whether the water spray is a food stimulus itself or acts indirectly by affecting the behavior of the live bait or the appearance of the artificial lures. Different species of live bait also result in different biting rates by skipjack, but this may be largely a consequence of the behavior of the bait in relation to the fishing boat rather than the releasing quality of each prey species (Yuen, in press). Some species, such as the anchovy, tend to swim toward the fishing boat when chased by tuna; other species, such as the goatfish, Mulloidichthys samoensis, tend to dive when chased by tuna.

2.3 Variations in response to food

Many physiological and psychological factors determine the internal feeding motivation and consequently the probability that an animal will respond to a given food stimulus. In Hawaiian waters as few as 43 percent (Royce and Otsu, 1955) and 52 percent (Yuen, 1959) of the skipjack schools contacted by pole-and-line fishing boats yielded any fish, which in turn implies that a large proportion of skipjack schools are not responsive to food stimuli.

Suyehiro (1938) and Hotta et al. (1959) both observed that biting rates of skipjack from a school were higher if the tuna had emptier stomachs. The development of plicae mucosa in the stomach walls was also associated with the emptiness of the stomach and the biting rate. Yuen (1959) observed that skipjack responded to chum for a longer period of time if their stomachs were emptier and if natural prey in the stomachs were in an early stage of digestion. He postulated that fishing boats often exploit a school already in an excited feeding state initiated by naturally occurring prey. Hotta et al. (1959) observed that skipjack with a high frequency of empty stomachs were also captured from poor biting schools and he postulated that the percentage of empty fish in a school determines the overall response of a school to food rather than the stomach volumes of the captured fish. Laboratory experiments (Hotta, 1960) subsequently demonstrated with Japanese mackerel, Scomber japonicus (-Pneumatophorus japonicus japonicus), that if a large percentage of fish in a school had empty stomachs, the school remained in the feeding area for a long time and fed actively. If a small percentage had empty stomachs, the school split into a group of fish congregated about the food and a group of satiated fish swimming at a greater depth. The fish with empty stomachs stopped feeding and joined the deeper school before they themselves ate enough to become satiated. The food consumption of each "hungry" fish in the school was less if a smaller percentage of the school was composed of "hungry" fish.

When skipjack in laboratory tanks were fed as much food as they would consume at hourly intervals throughout the day, the intensity of their response to food rapidly decreased from morning to midday, only to increase slightly again in late afternoon (Nakamura, E., in press). Uda (1940) and Suyehiro (1938) presented data indicating that skipjack bit better in early morning and possibly again later in the day. This pattern was not observed for skipjack in Hawaiian waters (Yuen, 1959). A successful feeding response is difficult to induce in captive skipjack at low light intensities (Nakamura, E., in press) and it is likely that tuna begin the day with empty stomachs. Japanese mackerel (Ii et al., 1953) and Atlantic mackerel (Kittel and Kämpfe,1954) were less active at night than during the day. Stomach volumes of skipjack from the Marquesas Islands and Hawaii followed a diurnal pattern indicating two periods of feeding, the first early in the morning and the second in midafternoon (Nakamura, E., MS). A diurnal rhythm in feeding behavior seems to exist in skipjack and it can be speculated that satiation of the food drive contributes to such a rhythm.

Not only are the volumes of food in the stomach associated with the biting responses of skipjack on pole-and-line fishing boats, but also the species of food in the digestive tract seem to have an influence. Skipjack which had been feeding on fast swimming fish bit faster and remained near the fishing boat for a longer period of time than skipjack which had been feeding on slow-swimming fish (Yuen, 1959). Skipjack schools near Hawaii dived away from the surface for periods of 3 to 28 minutes, more frequently if the occurrence of postlarval Synodus variegatus and juvenile Holocentrus lacteoguttatus in the stomachs was high (Strasburg, 1961). Skipjack with a high frequency of small crustaceans in the instestine bit better than those with a high frequency of fish in the intestine (Hotta et al., 1959). Skipjack feeding on natural food of the open ocean bit better than those feeding on coastal prey (Suyehiro, 1938). Mechanistic explanations for these and other similar correlations are difficult to verify at present.

3 SCHOOLING BEHAVIOR

Schooling behavior is observed in all scombrids except the wahoo. Schooling is characterized by a group (school) of fish swimming together in parallel courses with a relatively fixed distance between each fish (Breder, 1959). A definite mutual attraction exists between schooling individuals which in theory is cancelled by a repulsion between individuals when they approach within a certain minimum distance of each other (Parr, 1927; Breder, 1954).

Stimuli which release schooling behavior are mediated primarily by the sense of vision. Chub mackerel, Scomber colias (-Pneumatophorus colias), did not school if they were blinded by piercing their cornea (Shlaifer, 1942) or by placing opaque discs over their eyes (Parr, 1927). If the opaque blinders were removed, schooling was immediately resumed. Hatanaka et al. (1957) reported that Japanese mackerel formed a more compact school on dark nights than they did during daylight hours. Yet, in complete darkness chub mackerel did not school (Shlaifer, 1942) even though schooling persisted in deep red light, 650µ - 700µ, and in light intensities so low that the observer could just see the mackerel in the aquarium. Moonlight provided sufficient light for skipjack to school (Nakamura, E., in press). Tuna probably disperse in absolute darkness, but at times light from moonlight or perhaps even from the biological luminescence of zooplankters can be expected to provide enough light for schooling.

Stimuli which release schooling behavior among chub mackerel appear to be associated with the normal swimming movements of a companion and not with its coloration (Shlaifer, 1942). A chub mackerel would not school with a freshly killed companion towed through the water nor with a companion blinded in both eyes and apparently swimming erratically. Schooling did occur among living mackerel painted blue, white, or black.

Yellowfin, Thunnus albacares (-Neothunnus macropterus), and skipjack tend to school with other individuals of the same species and size (Broadhead and Orange, 1960; Brock, 1954). These conclusions are based upon the species composition of purse-seine and pole-and-line catches, and upon the size variability within and between schools. Schooling by species may occur because stimuli which release schooling are for the most part species specific. Brock (1954) hypothesizes that schooling by size results from difference in the swimming speeds of large and small fish. Swimming speeds of Japanese mackerel are more rapid for larger individuals (Hatanaka et al., 1957), but this observation in itself does not verify the swimming speed hypothesis above.

The schooling drive may wane as tuna get older. As mentioned above, schooling behavior is disrupted by feeding behavior. This disruption was apparently complete among large skipjack, 70-80 cm., whereas medium-sized skipjack retained some schooling behavior while feeding, and small skipjack, 20 cm., retained a great deal of schooling behavior while feeding (Strasburg and Yuen, 1960a). In addition, yellowfin caught on adjacent hooks along a longline have a smaller mean length than those caught solitarily along a longline (Brock, 1962). This latter observation indicated that large yellowfin are found in smaller schools than are small yellowfin.

Schooling behavior is relatively easy to observe for surface tuna, but direct observations of schooling behavior among deep-swimming tuna have not yet been made. Evidence for schooling among deep-swimming tuna comes from the distribution of tuna hooked along a set of longline gear. Hirayama (1957) observed a high frequency of tuna on adjacent hooks and by using a mathematical formula calculated a theoretical school width of 1,400-4,500 m. He concluded that a unit this large could not be behaving as a single unit and that the calculated width probably represented an aggregation of schools. The distance between tuna longline hooks is usually 50-60 m and fish occurring on adjacent hooks in pairs, trios, and even quartets could be expected to represent a unit held together by visual stimuli. Schooling would be indicated if the observed frequencies of such groups were greater than expected from fish distributed randomly along the line. Yellowfin (Brock, 1962; Maeda, 1960; Murphy and Elliot, 1954) and bigeye, Thunnus obesus, (Maeda, 1960) occur on adjacent hooks more often than would be expected by chance. According to Maeda (1960), albacore do not occur on adjacent hooks more often than expected by chance, but an examination of his Fig. 12 indicated that pairs of albacore occur more frequently than expected by chance in 31 out of 40 samples. Apparently deep-swimming schools of yellowfin, bigeye, and albacore do exist.

School size can be estimated if it is assumed that a purse-seine catch contains all the fish from a single school. In the eastern tropical Pacific the average catch per successful set was 12,927 kg for yellowfin or 12,564 kg for skipjack (Broadhead and Orange, 1960). In numbers this would be about 1,400 yellowfin and 2,800 skipjack. Although over 75 percent of the yellowfin and skipjack catches in the eastern tropical Pacific are between 227 and 18,144 kg, single sets have yielded as many as 104,326 kg of yellowfin or 117,934 kg of skipjack. These catches were estimated from Fig. 9 of Orange et al. (1957). Along the northeastern coast of Japan average catches per successful set of one-boat and two-boat purse seines respectively were 8,253 and 13,504 kg. of bluefin, Thunnus orientalis, 5,777 and 3,264 kg of yellowfin, or 5,702 and 7,765 kg. of skipjack (Inoue, 1959). Purse seining has been conducted only once in Hawaiian waters and only 590 to 3,828 kg of skipjack were caught per set even when bait was chummed to hold the fish (Murphy and Niska, 1953). Analyses by Broadhead and Orange (1960) indicate that skipjack schools in the eastern tropical Pacific are larger than those in Hawaiian waters.

4 ASSOCIATIONS

Tuna are frequently sighted at sea in the presence of other species of tuna (Orange et al., 1957; Postel, 1955), sharks (Kimura, 1954;

Uda and Tsukushi, 1934), forage fishes (Kimura, 1954), porpoises (Godsil, 1938), whales (Godsil, 1938; Kimura, 1954; Uda and Tsukushi, 1934), floating logs (Kimura, 1954; Uda and Tsukushi, 1934; Yabe and Mori, 1950), bamboo rafts (Kojima, 1960), etc. The percentage occurrence of these associations with skipjack varies markedly with geographical area and time of year (Kimura, 1954; Orange _et_ _al_., 1957; Uda and Tsukushi, 1934).

Associations between tuna species, tuna and birds, tuna and porpoises, and in some cases tuna and whales or sharks may be based upon a common interest in the same concentration of prey. Birds were observed to follow tuna and to prey upon small fish chased to the surface by tuna (Godsil, 1938; Royce and Otsu, 1955). Tuna fishermen take advantage of this association and locate tuna schools by seeking bird flocks. They even make inferences about the behavior of the tuna from the birds' behavior. The possibility that tuna use birds, porpoises, whales, or other tuna in locating concentrations of prey also exists.

Association with sharks also results from predation by sharks on tuna (Bullis, 1961; Springer, 1957).

Uda (1933) stated that skipjack concentrated about whale sharks, fin whales, sei whales, and floating logs to escape predators. Observations which lend some support to this statement were reported by Gudger (1940). Hypotheses mentioned by Yabe and Mori (1950) for association with floating logs are that tuna seek the shade of a floating object or that forage is more abundant near a floating object. Since tuna were not found in association with floating seaweed which would provide both shade and forage fish, Yabe and Mori (1950) argue that neither shade nor food is a factor. They further discounted food because drift-log schools took bait readily and did not appear to have a high abundance of small fish or zooplankters in their stomachs. Shade was considered unimportant by Kojima (1960), who observed that tuna and other fishes under anchored bamboo rafts did not stay in the shade but instead oriented upstream from the raft along the anchor line. Observations by divers under a salvage ship led Damant (1921) to conclude that the shadow of the ship made zooplankton more visible to mackerel which collected under the ship and fed on the zooplankters. Available evidence does not lead to a ready explanation for the association between tuna and whales or floating objects.

5 MIGRATORY BEHAVIOR

Tuna have long been known to make extensive migrations (Sella, 1929). In the Pacific tagged albacore have been recaptured as many as 6,920 km.from the place at which they were tagged, and have averaged as much as 0.98 km per hour during a 287-day period between time of release and recapture (Otsu, 1960). Such data and data on other species indicate that tuna possess highly developed orientation mechanisms which make directed movements across the seas possible. No work has been conducted to delineate these mechanisms for tuna, but kinesis in respect to temperature gradients and orientation in respect to celestial bodies or the angle of their light rays are two possibilities.

6 LOCOMOTION

Skipjack swim continually with their mouths agape, and pectoral fins slightly extended (Nakamura, E., in press). The first dorsal and pelvic fins are also extended during turns and all fins, including second dorsal, anal, and ventral fins, are extended during sudden deceleration. Swimming speeds of skipjack in a feeding school have been clocked at sea at 6.4-7.7 meters per second (Watanabe, 1942).

7 REPRODUCTIVE BEHAVIOR

Observations of reproductive behavior have not been reported.

8 SENSORY PERCEPTION

The eyes of Japanese mackerel have a lower ratio of twin to single cones than do non-scombrid fishes dwelling at depths of 100-300 meters, and Tamura (1957) postulated that twin cones are more sensitive to low light intensities than are single cones. Although cone densities are higher in the posterior half of the retina, indicating greater acuity to the front, no area of the retina is highly specialized for acute vision. The ratio of highest cone density to lowest cone density from different areas of the retina is only 1.21, whereas in non-scombrids this ratio is as high as 7.46.

According to Tamura (1957), the even distribution of cones may have advantages to pelagic fishes by providing balanced vision in all directions. Estimates of visual acuity based upon the angle subtended by one cone indicated that relative to other fishes the Japanese mackerel has average acuity.

A well developed pineal apparatus, consisting of a pineal window, pineal tube, pineal dome, and pineal organ, has been described in bluefin, Thunnus thynnus, and many other scombrids by Rivas (1953) and Holmgren (1958). These structures permit light to be transmitted from the top of the fish's head to the pineal region of the brain. The pineal tube is at an angle of 20°-30° from the vertical and would be expected to pass the greatest amount of light to the pineal region when the sun was 45°-60° above the horizon (Rivas, 1953). Rivas postulated that the pineal apparatus is involved in the positive phototaxis described by Hsiao (1952) for yellowfin and little tunny in response to light intensities between 70 and 450 ft.-c. Although histological and anatomical evidence for a sensory role of the pineal apparatus in tuna is good, this has not been verified with behavior data (Holmgren, 1958).

Tester et al. (1955) and van Weel (1952) demonstrated that tuna are able to perceive tastes or odors found in extracts of shrimp, squid, and tuna flesh. The detectable substance (substances) did not appear to be a fatty acid or lipoid, an amino acid or protein, or a purine but in many respects chemically resembled vitamin B_{12}. Tuna were also repelled to a small degree by copper acetate, a shark repellant.

The characteristics of a sense of hearing have not been described for tuna. The Japanese mackerel turned away from a small explosion if the sound intensity exceeded 58 db. and responded to the sound of a bat hitting a wooden barrel at intensities of 35-38 db. (Suyehiro et al., 1957).

9 PHYSIOLOGY

Scombrids bring oxygenated water in contact with the gill filaments by swimming continually with their mouth agape. When forward motion of a mackerel was impeded, oxygen saturation of the blood decreased from 85 percent to 11 percent (Hall, 1930). In contradiction to the above, Kittel and Kämpfe (1955) reported that Atlantic mackerel come to rest near the bottom at night. The anatomical structures necessary for pumping oxygenated water over the gills are poorly developed. Gray (1954) found that the gill area for Atlantic mackerel was 1158 mm ^{2} per gram of body weight. This was the second highest relative gill area among 17 temperate-zone marine fishes examined. Oxygen capacity of the blood, 15.77 ml. oxygen per 100 ml. of blood (Root, 1931), and the amount of iron, 43.8 mg. per 100 ml. of blood (Hall, 1930), were also high relative to other fishes. Scombrids are apparently capable of providing relatively large amounts of oxygen to their body tissues, which is not surprising when their high activity levels are considered. Oxygen consumption by a 138-g mackerel was given by Baldwin (1923) as 0.726 cc. of oxygen per gram of body weight per hour, which was the highest rate among eight marine fishes he examined. High metabolic rates are also indicated by body temperatures of yellowfin, bigeye, and skipjack, which are apparently 1°-4° C. higher than the temperature of the surrounding water (Nakamura, H., 1941; Watanabe, 1942; Uda, 1941).

Amount of food eaten per unit body weight, relative growth rate, and efficiency of food conversion decreased as the size of Japanese mackerel increased (Hatanaka and Takahashi, 1956; Hatanaka et al., 1957). Mackerel 33 g in weight, reared at 20°-22° C and fed as much anchovy as they would eat, ingested 18 percent of their body weight per day with a 20-percent conversion efficiency, whereas mackerel 73 g in weight ingested only 10 percent of their body weight per day with a 15-percent conversion efficiency. Feeding rates, growth rates, and conversion efficiencies were lower at lower temperatures. Immediately after a period of starvation mackerel ate more, grew faster, and had higher conversion efficiencies than they did 10 days after the period of starvation ended. When amounts of food given per day were increased, feeding rates and growth rates increased, but efficiency of conversion decreased. Estimated amounts of food needed to just maintain body weight were 4.7, 4.1, and 3.6 percent of body weight for 7-24 g, 26-48 g, and 50-95 g mackerel respectively. Daily rates of catabolism, estimated from daily loss in weight when not fed at all, were 1.96, 1.12, and 0.80 percent of body weight for 7-24 g, 26-48 g, and 50-95 g mackerel respectively. A comparison of anchovy and *Euphausia* as food demonstrated that conversion efficiency was less for *Euphausia*. Hatanaka et al. (1957) believe that the lower efficiency with *Euphausia* may result from the larger proportion of indigestible material in *Euphausia* compared to anchovy. The above experiments yielded higher growth rates than were observed in natural populations of mackerel, and Hatanaka *et al*. (1957) estimated that growth rates observed in nature would be approximated if a young-of-the-year mackerel ingested 375 g of anchovy and 1553 g of *Euphausia* during the year, and if a one-year-old mackerel ingested 968 g of anchovy and 3660 g of *Euphausia* in a year. The ratio of *Euphausia* to anchovy was determined from the occurrence of these two types of food in mackerel at sea.

Studies on Japanese mackerel indicated that after eating to satiation the stomach contents were reduced in volume by about 90 percent after 8 or 10 hours (Kariya, 1956). At that time the contents had been reduced to gurry which was moved into the intestine 21 hours after ingestion. At intervals after satiation food was eaten approximately equal in volume to the amount of food removed from the stomach by digestive processes. During the digestive process the stomach contents are acidic (Kariya, 1956).

Although additional information is available on tuna physiology, especially in the Japanese literature, no attempt was made to review it at this time.

10 METHODS OF STUDY

Methods of collecting data useful in describing and understanding behavior of tuna include (1) indirect observations on tuna at sea, (2) direct observations of tuna at sea, (3) direct observations on captive tuna, (4) comparative studies of tuna anatomy and histology, and (5) any of the methods, referred to above, which have been used to study mackerel or other species closely related to tuna. Indirect observations at sea have been obtained with sonar (Anonymous, 1953; Anonymous, 1961; Lozano Cabo, 1959; Nishimura, 1961), from observations on bird flocks, from tagging and recapture data, from spatial distributions of tuna on longlines, and from catch rates, stomach contents, and associated data from purse-seine and pole-and-line fishing. Most published data relevant to tuna behavior have been collected by these indirect methods.

Except for observations through the water's surface from ships, direct observations at sea of behaving tuna are a very recent advance. At present observations are made from underwater ports in surface vessels (Strasburg and Yuen, 1960b.), from low flying aircraft (Royce and Otsu, 1955; Hotta *et al*., 1961), by SCUBA divers from floating rafts (Kojima, 1960), from small wet submersibles, and in the future observations using mesoscaphes may be practical (Zaitsev and Azhazha, 1959). Direct observations are necessary for most types of behavior studies and are a prerequisite to the description and understanding of tuna behavior. Such observations are difficult to obtain at sea, since the proportion of time spent actually observing behavior is low owing to difficulties in either keeping the observer near the tuna or, conversely, the tuna near the observer. Many of these difficulties can be removed by using captive tuna in shoreside enclosures or tanks for study. Work by Tester (1952), and Nakamura, E. (1960, in press) have demonstrated that studies on captive fish, although difficult, are now possible. Ethograms can be made and analyzed, salinity and temperature preferences can be measured, sensory acuity, motivation, and learning can be studied. Inferences about behavior and clues as to what to look for in behavior can result from studies of anatomy and histology. These studies are more useful if they are comparative in scope. Much of the detailed information on schooling and feeding behavior presented in the present summary have had to be generalized from studies on mackerel because equivalent data are not available on tuna. These studies are most useful and will continue to be useful, because there are many similarities between mackerel and tuna, and because mackerel are more easily handled in the laboratory.

11 THE FUTURE

The above summary of information on the behavior of tuna demonstrates the presence of many unknowns and many unverified hypotheses. An overwhelming number of potentially fruitful studies await the researcher of tuna behavior. Accurate descriptions of behavior characteristics, the basis of any ethological study, have not been completed, much less compiled into feeding ethograms, reproductive ethograms, etc. The physiological basis and the ecological consequences of behavior provide opportunities for study of color changes, fin movements, mouth movements, diving behavior, sensory systems, etc. Sensory acuity is unknown for vision or sound perception. Mechanisms of migration orientation are unknown for tuna. Phototaxis and the potential role of the pineal apparatus should be clarified. An ethological explanation of size and species homogeneity of schools can be expected to result from careful experimentation, as can ethological explanations for associations between tuna and porpoise, whales, or floating logs. Studies are needed on detailed histology and anatomy of sense organs, central nervous system, and muscular system. As many or more unknowns are to be found in tuna physiology as in behavior.

The greatest advances in the study of fish behavior have come from studies conducted on species easily reared in the laboratory. Although many papers are to be found in fishery literature which pertain to tuna behavior, ethological and psychological literature contain no papers on tuna. The present status of our knowledge on tuna behavior suffers from difficulties in studying the animals inexpensively in the laboratory. Newly found skills, such as the ability to hold tuna in captivity, the ability to make direct observations at sea, and the ability to follow their movements with sonar, will provide the tools for many interesting studies in the future.

Methodological Paper No. 6

FISHING TECHNIQUES FOR TUNAS AND SKIPJACK

By

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Abstract

Recent years have brought a substantial increase in the demand for skipjack and other tunas in the major markets of the world. This has been accompanied by an increase in fishing effort. The principal types of tuna fishing methods are (1) line fishing, including pole-and-line, trolling, and longline, and (2) net fishing, including drift net, purse-seine, and set net or trap net. Descriptions are provided of the various types of gear, how they operate, and in what countries they have been developed and are presently employed.

Most tuna fishing boats are either pole-and-liners (live-bait boats), longliners, or purse-seiners. Large numbers of U.S. west coast live-bait boats, recently converted to purse-seining, have had phenomenal success. The advent of very large, light-weight nylon seines and the power block have made it possible.

Comparisons are given of the relative effectiveness of the different kinds of gear and of operations with the same kind of gear in different parts of the ocean and in different countries. The author proposes that the following items be the subject of future research programs: (1) behavior of fish as a school, (2) identification of fishing grounds, (3) predation by natural enemies, (4) aids for formation of fishing grounds, and (5) electrical fishing.

TECHNIQUES DE PECHE DU THON ET DE LA BONITE A VENTRE RAYE

Résumé

Ces dernières années, la demande de bonite à ventre rayé et autres thons a connu une forte augmentation sur les principaux marchés mondiaux. Cette évolution s'est accompagnée d'un accroissement de l'effort de pêche. Les principales techniques de pêche du thon sont: 1) lignes, y compris pêche avec canne et hameçon, lignes de traîne, et palangres; 2) filets, y compris filets dérivants, sennes tournantes et filets fixes ou trappes. La communication décrit les divers types d'engins et leur fonctionnement, et indique les pays dans lesquels ils ont été mis au point et sont actuellement employés.

La plupart des thoniers sont des bateaux de pêche à la canne et à l'hameçon (utilisant des appâts vivants), des palangriers, ou des senneurs. Sur la côte ouest des Etats-Unis d'Amérique, un grand nombre de bâtiments pratiquant la pêche à l'appât vivant ont récemment été transformés en senneurs et ont obtenu des résultats phénoménaux. Ce succès a été rendu possible par la mise au point de sennes en nylon de très grandes dimensions et très légères ainsi que du "power block" (poulie mécanique).

La communication compare l'efficacité relative des différents types d'engins ainsi que de la pêche avec le même engin dans différentes zones marines et dans divers pays. L'auteur propose que les futurs programmes de recherche portent notamment sur les points suivants: 1) comportement des poissons en bancs; 2) identification des lieux de pêche; 3) prédation exercée par les ennemis naturels; 4) moyens de créer des zones de pêche; 5) pêche à l'électricité.

TECNICAS DE LA PESCA DEL BARRILETE Y OTRAS VARIEDADES DE ATUN

Extracto

En los últimos años ha aumentado considerablemente la demanda de barrilete y otros atunes en los principales mercados mundiales. A esto ha ido unido un mayor incremento del esfuerzo pesquero. Los principales métodos de pesca del atún son: (1) con líneas, entre las que figuran la caña y el sedal, el curricán y el palangre, y (2) con redes, que comprenden las de deriva, cerco de jareta, fijas o trampas. Se describen varios tipos de artes y aparejos, su funcionamiento, los países donde han sido introducidos y en los que se emplean actualmente.

La mayoría de los barcos atuneros trabajan con caña y sedal (cebo vivo), palangre o red de cerco. Muchísimos de los barcos que operan con cebo vivo en la costa occidental de los Estados Unidos se han pasado últimamente a la red de cerco con estraordinario éxito, lo que ha sido posible gracias a los nuevos artes de nylón, de grandes dimensiones y muy poco peso, y a la introducción del motón mecánico.

Se establecen comparaciones entre la eficacia relativa de los diferentes tipos de artes y aparejos y entre las operaciones con un mismo aparejo o arte en distintos lugares del océano y en diferentes países. El autor propone la inclusión de los siguientes temas en futuros programas de investigación: (1) comportamiento del pez como cardumen; (2) identificación de las pesqueras; (3) ataques por enemigos naturales; (4) medios o auxilios para la formación de pesqueras, y (5) la pesca con electricidad.

1 INTRODUCTION

With the substantial increase in demand for tunas and skipjack in major markets of the world, commercial fisheries in various countries have been increasing their effort to capture these species. Regional differences in fishery development are, of course, dependent upon the geographical distribution of fish, which is governed by biological and environmental factors, and on the social and economic needs of each country in respect to fish consumption. Usually the fishing industry in a country develops according to the size of the capital investment in fisheries, which is in turn influenced by the level of her general industrial advancement.

In a region close to the ocean or sea where schools of tunas migrate frequently, the adoption of suitable gear and methods may not require highly efficient vessels having a wide navigational range. On the other hand, little progress in fisheries development has been seen in countries where catches of tunas or skipjack are not so much utilized or evaluated as elsewhere.

At present one of the major fishing techniques for tunas and skipjack is line fishing developed in Japan and the United States and mainly comprising pole-and-line and longline fishing methods (Shapiro 1948; Cleaver and Shimada 1950; Imamura 1951). The other principal technique is the U.S. type of purse-seine fishing as employed in waters off California (Scofield 1951; Shimada and Schaefer 1956).

Tuna traps used in Italy and Spain are special gear limited to these regions (General Fish. Council Medit., 1961). In Japan, trap nets which were once designed for tunas have been replaced with nets for various other species of fish.

2 MAJOR TYPES OF FISHING TECHNIQUES

The wide distribution of these fish and the expanding fisheries for tunas and skipjack make it almost impossible to classify tuna fishing gear and methods by region. Instead, it is more feasible to sort them into:

1) Line fishing
    - i) Pole-and-line (including hand line)
    - ii) trolling
    - iii) longline

2) Net fishing
    - i) drift net
    - ii) purse-seine
    - iii) set net or trap net.

2.1 Comparative efficiency between line and net fisheries

One type of gear differs from another in characteristics related to its construction and usage and also in respect to the bionomics of fish sought and oceanographic conditions pertinent to the particular fishery. These factors make it difficult to determine the efficiency of various types of gear on a comparable basis. The average catch per unit of effort for a certain type of gear may be different from area to area. Even under the same conditions as to time, locality, and type of gear, the results vary widely depending on the skilfulness of the fishermen (Cleaver and Shimada 1950; Yoshihara 1954; Hamuro and Ishii 1958). Generally speaking, however, line fishing can be regarded as a rather passive method in which the amount of catch is proportional to the number of hooks used. For this type of gear it is not always necessary to have a dense school of fish. Among net fisheries, drift nets, set nets and trap nets are also passive as they are dependent on the behavior of the fish. In contrast, the purse-seine is a mobile and aggressive gear which needs, for operation, a highly dense school of fish swimming in the surface layer.

2.2 Pole-and-line fishing

In pole-and-line fishing for tunas and related species in various countries of the world, the most common feature up to the present time is the use of live bait. The use of tuna clippers has been developed on the Pacific coast of the United States. The FAO Yearbook (1960) shows the existence of this type of fishing in France, as well. Japanese fishermen have employed the pole-and-line method mainly for skipjack, Katsuwonus vagans, though they recently started applying the technique to catch albacore, Germo germo (Shapiro 1948; Cleaver and Shimada 1950). In the pole-and-line operation, baiting and unhooking have to be done in a minimum time therefore the use of barbless hooks is another common feature of the fishery.

The success of pole-and-line fishing is dependent upon, among various factors, the supply and maintenance of live bait. In Japan, the commonly used bait fish are sardines or anchovies which are acclimatized and kept in a confined environment in a sheltered area. Prior to each trip, pole-and-line fishermen purchase a supply of small fishes from bait fishermen and keep them in a live-bait tank which is installed in the well deck basin at the bow of their vessel. Sea water is circulated in and out, as the boat proceeds, through holes bored in the bottom of the tank.

Tuna clippers of the United States catch bait fish for their own use and maintain them in a tank placed on the quarter deck with water circulated by means of a powered pump. The position of the bait tank on U. S. tuna clippers limits the fishing platforms to the stern (Carlson 1954; Muramatsu 1960).

In order to compensate for a short supply of sardines or anchovies as bait, which is sometimes the case, tilapia and shad have been tried (Ikehara 1953; King and Wilson 1957). As substitutes for live baits, jigs or odoriferous chemical agents which attract fish by either eyesight or smell have been tested with various degrees of success (Tester 1959; Tominaga 1957).

Another idea for inducing tuna to form a school is to take advantage of their habit in following or taking shelter under a floating substance such as a drifting timber or log. For this purpose, use of a timber dressed with artificial seaweed or a plastic float of similar shape has been proposed in Japan.

It is primarily the Japanese fishermen that use a water spray system in the pole-and-line operation. Apparently the shower of water blocks out the shadow of the boat, excites the fish, allows them to be hooked more readily and reduces the use of live bait. When a fish finder locates a sub-surface school of fish, they can be led to the surface by the use of chum. A powerful light used at dusk can extend the operation time for skipjack fishing by a few hours. All of these techniques, and their improvement, may deserve attention.

Roughley (1950) described the use of helicopters for scouting schools of fish for tuna clippers operating in the sea adjacent to Australia. No detailed information on subsequent developments is available.

2. 3 Trolling

Although trolling is another type of fishing method for catching skipjack and tunas, adoption of this method to commercial fishing is limited to coastal waters in most countries (Johnston and O'Gradey 1951; Van Pel 1955; Scofield 1956). The method is frequently used for scouting a latent school of fish in an expected fishing ground (Cleaver and Shimada 1950).

In operation, artificial bait is often used in addition to live bait. Japanese fishermen attract the fish by trolling hookless jigs. Utilization of a low frequency pulsative current for trolling was first conducted in West Germany and then developed in some North European countries as well as in Japan (Kreutzer 1951; Meyer-Waarden 1955; Nagai 1955). As this technique is presently adaptable only for fishing in the surface or sub-surface layer, attempts have been made to improve it for deep water operation by the use of a sinker, or depressor (Nagai 1955; Dethloff 1959). There is also need for further improvement of the gear from the point of easy handling.

2. 4 Longlining

In contrast with pole-and-line and trolling which seek after fish in the surface layer, longline is effective mainly for tunas which swim in deeper layers of the sea in a generally dispersed distribution.

The principle of the gear construction is to suspend from the main line a number of branch lines each carrying a hook at the lower end. The depth to which the hooks are lowered is adjustable by changing the distance between floats or by using different lengths of float line.

Baits used on the longline include fresh or frozen sardine, saury, mackerel, and squid; occasionally live bait or artificial lures are used as well (Shomura 1955; Koyama 1957a and b; Ikeda 1958).

Since the advent of man-made fiber for fishing nets and ropes, main lines and branch lines have been ordinarily constructed with synthetic multifilament fiber. The leader attached to the hook is usually made of wire. The idea of using wire for both the main line and the branch lines has opened up the possibility of mechanizing the hauling operation for further commercial development (Mann 1955 and 1957). In Japan, physical properties of longline materials have received considerable attention (Nagai 1959; Honda 1960; Sunami 1960; Shimozaki 1960 and 1962).

The quantity of longline employed in an operation governs the amount of catch per haul. The catch is also dependent on the scale of fishing (for instance, size of a boat), oceanographic conditions, abundance of fish, and so forth. In Japan the unit of longline is the "basket" since the main line is coiled like a basket for storing. A fishing boat ranging from 200 to 800 gross tons in size usually carries 350 to 400 baskets of longline, each measuring 200 to 250 m in length. A tuna mother ship may carry portable dinghies aboard, as small as 20 gross tons, that can handle as many as 300 baskets of the line in an operation. The maximum number of baskets per operation, however, is about 400 on account of the length of time needed for setting and hauling in the line. Usually every basket has 4 to 6 branch lines each bearing a hook.

Further development of tuna longline fishing is dependent on commercial application of means to intensify a school of fish or to improve gear construction. There have already been a number of attempts to analyze relationships between the swimming depths of tuna and the depth for setting the longline, between distribution of catch and efficiency of the present gear construction. Some of these proposals suggest directions in which the longline will be further developed (Morita 1956; Yoshihara 1954 and 1961; Graham and Stewart 1958; Hamuro and Ishii 1958; Watanabe 1961).

2.5 Drift-net fishing

In the early 1900's drift nets were employed on a small scale, often for the purpose of scouting the distribution of skipjack and other tunas. In some parts of Southeast Asia a number of drift nets are presently operated for small-sized skipjack and other tunas.

Net construction including size of twines and mesh is varied according to the size of fish to be captured, which varies from region to region. In constructing a net for large-sized fish, the kinetic energy of the fish should be taken into account in determining the size of twine and the floatation of the gear. Usually drift nets for large-sized tunas do not carry sinkers as they are constructed on the principle of tangling nets.

In brief, drift nets are effective for catching those schools of fish that swim about on the surface in their migration from region to region.

An account has been published of experimental gill-net fishing for skipjack in Hawaiian waters (Matsumoto 1952).

2.6 Purse-seining

Purse-seining for tuna has been developed mainly on the Pacific coast of the United States. Although the purse-seine technique was introduced to Japan in 1880, commercial application of an American type of tuna purse seine had not taken place before 1947. Failure to adopt the American tuna purse-seine on the western side of the Pacific immediately after the second World War can be mainly attributed to differences in behavior of the fish and in oceanographical conditions between the eastern and western side of the Ocean. Also, most tuna purse-seiners in Japan had independently developed a two-boat system of operation (Suzuki, M. and K. Suzuki 1959). According to available information, Norwegian fishermen use purse-seines for catching tunas migrating close to shore in North European waters. Few of their purse-seiners, however, are built on a large scale, possibly because of the limited fishing season and the small size of the tuna stock on the fishing ground. In this regard, Meyer-Waarden (1959a and 1959b) drew attention to the fact that the tuna stock to be exploited by the Norwegian purse-seiners apparently belongs to the same population sought after by hook-and-line fishermen in Sweden, Denmark and Germany. In the sea adjacent to Japan, the catches of longliners and purse-seiners frequently differ in respect to the length composition of the tunas.

The recent success of the U.S. purse-seiners converted from tuna clippers is a remarkable example of how an established fishing method can be improved. The conversion of tuna clippers to seiners has been occurring at a fast rate. This phenomenon is attributable to the development of large nylon nets along a power block for hauling the nets (Schmidt 1959); McNeely 1961). Removal of the bait tank from the quarter-deck of the clippers made it possible to instal a net turntable in that place, with no critical change in the ship's balance.

In regard to their construction, U.S. purse-seines are simple but yet durable enough for mechanical handling. The cork line selvedge strip is "hung in" to the cork line at 10 to 12 percent; the net is shallow in depth with the ratio of length to depth being 10: 1 (McNeely, 1961). On the other hand, Japanese tuna purse seines are "hung in" from 20 to 30 percent, according to the size of fish sought and oceanographic conditions on the fishing grounds. The ratio of length to depth is about 10: 2, but the actual length of net may be twice as great as the American tuna purse-seine, because of the difference in hanging ratio (Suzuki, M. and K. Suzuki 1959).

At present in Japan each tuna purse seine is operated by a pair of boats, each of about 50 gross tons and 300 hp. One of the boats, or sometimes, both, carry a net hauler. The number of fishermen needed for the two-boat operation is 50 to 60. In the event that the Japanese purse seine is mechanized with help of the power block, construction of the net should be altered to make it more durable even at the sacrifice of some of its functional advantages.

2.7 Set-net fishing

The decrease in the number of tunas frequenting Japanese coastal waters was followed by an increase in the abundance of other species. Tuna set nets disappeared from Japanese waters and a modified set net, "otoshi-ami", capable of entrapping almost any kind of fish , took its place.

It is recommended that set nets be made of knotless net fabrics of synthetic fiber. Synthetic fiber ropes still have some undesirable qualities, however, such as stretching and their high cost.

Perhaps one of the most typical set nets for tunas is the trap net operated off Sicily in the Mediterranean Sea. A publication from the Secretariat of GFCM (1961) gives a detailed account of Sicilian tuna traps. Other tuna traps seen on the coast of Spain and Libya are of similar construction to the Sicilian type. Apparently no remarkable technical changes have been introduced into this gear during the last 50 years. In Sicilian tuna traps, however, a leader net called the "costa" seems to be effective, differently from the function of the leader in Japanese set nets by leading into the trap schools of tunas that swim in a fairly wide range of the coastal water. Sicilian trap nets have the leader net equipped with a "campile" (projecting wall net), and the entrance of each chamber is designed according to the idea that tunas entrapped will in most cases swim around counter-clockwise in the net. This is an interesting similarity in design between the Sicilian and the Japanese set net.

As the Sicilian fishermen aim to capture large-sized tuna, they prefer net twines and ropes relatively thick in size. Like Japanese fishermen, they also haul up their traps by manpower. In Japan attempts at using compressed air or a ring line system for hauling-up operations have not been successful enough for commercial adoption (Takayama et al 1931; Miyamoto 1950).

3 MAJOR TYPES OF FISHING BOATS AND THEIR EQUIPMENT

3.1 Fishing boats

Most tuna fishing boats are either pole-and-liners, longliners or purse-seiners. The first group is represented by the U. S. western style of tuna clipper, the Japanese clipper for skipjack and albacore, and the French tuna clippers; the Japanese longliner is the champion of the second group while the U. S. western-style seiner is the best of the third type.

The U. S. clipper has a live-bait tank, an essential installation, at the quarter deck with water circulated by means of a powered pump. In Japanese clippers, the bait tank is installed at the well deck basin on the bow side with water freely flowing in and out through a hole. The fishing platforms are located principally at the stern in U. S.-type boats, while they extend from bow to stern on Japanese clippers, with preference of either the port or the starboard side depending on local practice. Shower nozzles placed at 2 m intervals along the fishing platform are something unique to Japanese clippers. The purpose is to excite the fish and to reduce the shadow of the boat at the time of operation (Hanson 1955; Takagi 1955; Muramatsu 1960).

Japanese tuna longliners have a spacious well deck at the bow for line-hauler operation as well as for handling the catches. Setting the line is done at the stern. Under the well deck the fish hold is furnished with refrigeration pipe (Takagi 1955; Kanasashi 1960).

A representative U. S. tuna purse-seiner generally resembles a U. S. tuna clipper in its hull structure. However, the former has a net turntable at the stern in place of a bait tank and is equipped with a 5-ton hydraulic winch with three drums,for handling the purse lines, and a heavy duty derrick or boom. The derrick carries at its top a power block driven by a hydraulic motor (Schmidt 1959; McNeely 1961).

Japanese tuna purse-seiners used to have on the quarter deck a net hauler driven by means of a shaft from the main engine. Recently a hydraulic net hauler has superseded the old-fashioned machine (Kumagori 1960).

In respect to general deck arrangement, U. S.-style seiners and clippers have the work deck and bait tank at the stern and the bridge and engine forward. Japanese clippers and longliners, however, have the work deck and the fish hold in the forward position, the bridge near the center, and the engine at the stern.

3.2 Mother-ship operation

In addition to individual tuna boats operating from their bases, Japan uses another important system, that of a mother ship which serves as a mobile base at sea for a fleet of longliners. This arrangement results in fewer trips back and forth to the fishing grounds and greater economy of time and fuel (Shimada 1951; Ego and Otsu 1952). Some of the tuna mother ships carry a few dinghies, each of about 20 gross tons and yet capable of fishing 300 baskets of longline. If the mother ship is of the 1,000-gross-ton class, she can also operate the longline herself.

3.3 Line haulers

Most of the Japanese tuna longline haulers have an upright type of winding pulley driven by a shaft from a 15 h.p. electrical motor. Usually two line haulers are installed in series on the starboard side, one of them being for auxiliary use. Normally the shaft works at 200 to 300 r.p.m., and hauls the line at 180 to 250 m per min (Yagi 1955; Izui Iron Work Co. 1959).

3.4 Power block

Present models of the power block aboard U.S.-style purse-seiners work from a central hydraulic system which provides 1,200 pounds pressure per square inch through a pump with capacity of 36 g.p.m. The high pressure line is 1-1/4 inches, and the one for low pressure drainage is 1/2 inch in diameter (Schmidt 1959; McNeely 1961).

3.5 Fish finder

Duties of fish finders installed on Japanese tuna boats not only to include sounding depths, banks and sea mounts where fish may occur but also to measure such oceanographic features as deep scattering layers and tide rips, and further to detect stray individual fishes. To meet these requirements, the transmitted 200-kc ultra supersonic wave was increased to 60 to 800 per min., with an in-put power of 2 to 3 kw. Efforts have been given to developing a powerful vibrator which can locate tunas swimming as deep as 250 m below the surface (Kimura et al 1952; Hashimoto and Maniwa 1959; Nishimura 1961 a and b; Hirano unpublished).

Much has been expected of fish finders working in horizontal directions, such as the "ASDIC" installed on some U.S. tuna purse-seiners. McNeely (1961) reports, however, that a majority of American fishermen still detect the occurrence of tunas by eye aided by a pair of binoculars.

3.6 Radio buoy

Since the Japanese use longlines of 40 to 60 miles per setting and there is always the risk of breaking the line halfway, the tuna longliners employ radio buoys. Each boat will have its own transmitting signal. Automatic gap transmission has been adopted to save the power source (Midorikawa 1959).

4 COMPARATIVE EFFECTIVENESS

Prerequisites for determining an adequate type of gear, method, and an optimal scale of operations for a fishery are knowledge of the behavior of the fish sought, the amount of fish normally available for the operation, as well as the economics of the operation. Under these prerequisites one may compare effectiveness between different or similar types of gear, each operated for the same species of fish at a given time.

4.1 Comparison between different types of gear

The amazing increase in purse-seiners converted from tuna clippers on the U.S. Pacific coast indicates superiority of the former as is perhaps related to the concentric configuration of tuna schools. Apparently this trend might have been accelerated by difficulties that pole-and-liners often have in securing required amounts of live bait. Jigs and other artificial baits do not always replace live ones (McNeely 1961). But skipjack fishing off Japan represents a contrary situation. In the reach of the Kuroshio Current sweeping the islands, which skipjacks frequent, both the fish and the current run pretty fast. Also, Japanese pole-and-liners have the opportunity to buy all the bait (sardine or anchovy) they need from bait fishermen before they start on a fishing trip. Although the mechanization of the gear could be improved, skipjack purse-seining more often fails because of adverse oceanographic conditions. Most skipjack pole-and-liners in Japan are built in the so-called combination style so that they may fish for tuna with longline during the off-season for skipjack (Takagi 1955). Despite the relative efficiency of the pole-and-line operation, development of skipjack fishing has been held back by a low market price of the fish and the trouble of finding the man-power of 30 to 50 anglers per boat.

In comparing U. S. purse-seiners and Japanese longliners, one must remember that both groups of fishermen are in search of tunas which are different in their ecological status from those sought by the other. The U. S. purse-seiners seek pelagic schools of tunas in the surface layer, just as do most of the U. S. tuna clippers, and the Japanese skipjack liners and seiners. The Japanese tuna longliners are different, however, since they are after tunas migrating at mid-water depths of 60 to 200 m. The longline operation is suited to fish that occur in dispersed fashion over a wide expanse of sea. Setting and hauling in the line takes 10 to 20 hours, depending on the number of baskets. These differences in conditions make it difficult to compare the effectiveness of longline with any other type of fishing gear.

The relation between the Mediterranean trap nets and other types of gear may be similar to that which the Japanese tuna longline bears to the others, because regional requirements play an important part in choosing a particular type of fishing gear. For this reason it is necessary to consider whether or not regional requirements and characteristics of any one type of gear permit a comparison of its effectiveness with gear of another region.

4. 2 Comparison between similar types of gear

4. 2. 1 Between purse-seines of Japan and the U. S. A.

In comparison with the Japanese type, tuna purse seines of the U. S. seem to be simpler yet more rational and more durable in construction. This may have resulted because their construction had to be simplified for mechanical handling of the net. A point in favor of the U. S. purse seine is that a net of 770 m in the corkline length can be operated by only 12 to 18 fishermen aboard a seiner of 150 gross tons. Because of the behavior of tunas occurring in waters adjacent to Japan, purse seines of Japanese type are larger in size and have more complicated construction, with the corkline length as much as 1,500 m, the depth varying from part to part of the net, and contraction twice or three times as much as the U. S. type. Therefore 50 to 60 men are needed to operate a Japanese tuna purse seine. Since Japanese seiners operate on the two-boat system as described earlier, it is possible for them to encircle fish in one half the time that is needed for an American one-boat seiner to do the work with a net having the same corkline length. In addition, Japanese seiners have an advantage in being able to change the encircling direction, whenever necessary, in accordance with the movement of the fish. Each of the two boats starts hauling in from the wing side first, thus the bag comes in last. This relieves the work of "over turning" the net which is otherwise needed before a subsequent setting. But the "haul-in" of Japanese seines calls for greater man-power because shortening of the net offsets efficiency of the net hauler. Along with these benefits and losses, one should still remember that an attempt in 1947 to introduce the American tuna purse seine to Japan ended in failure, probably because of oceanographic conditions and the behavior of the fish.

4. 2. 2 Between longlines differently built

Usually the results of longline fishing are expressed by the hooking-rate or the number of fish caught per 100 hooks. Although hooking-rate represents the mean value for all the hooks used in an entire set of the line, sampling of fish from the fishing ground inevitably involves bias because of uneven distribution of fish. Differences in detailed construction and operational procedure exert influences upon catches. In recent studies on the mechanics of the fishing operation, Japanese authors discussed such topics as the relationship between swimming layer and hook-depth, and hooking-rate pertinent to behavior of the line.

Some of these studies revealed that the depth of a hook may be estimated by calculating: (1) drift of the main line from a normal angle formed with the line and the direction of the current, and (2) relation between drift and sinking force of the branch line. Hooking-rate differs from basket to basket, because the first basket, for instance, stays in water usually more than 15 hours longer than the last basket when the line is set over a distance ranging from 40 to 60 miles. Since each basket usually carries 4 to 5 branch lines on different positions, they are inevitably lowered to different depths. Thus the catching frequency of a branch line in one basket has a certain tendency different from other branch lines in the same basket.

hooking-rate per basket is not only proportional to the duration of time hooks are in the water, but also is influenced by underwater performance of the hooks. Hooking-rate tends to drop when a branch line drifts up near the main line. These findings suggest that branch lines placed near the float line, which is vertically buoyed up, may have a lower hooking-rate (Yoshihara 1954 and 1961; Hamuro and Ishii 1958; Morita 1956; Watanabe 1961).

The author wishes to point out also that hooking-rate may be affected by inclination of the leader wire and the visual effect of the bait as a result of its shape, position, and behavior.

The factors enumerated above suggest that hooking-rate of longline is dependent upon the construction and operational procedure of the gear.

5 SELECTIVITY OF VARIOUS TYPES OF GEAR

5.1 Line fishing

After we observe the feeding activities of tunas and skipjack we do not expect a high selectivity in line fishing gear for fish which are large enough to be caught with a hook. Theoretically speaking, when a hook is too large or too small, it will never catch a fish. However, within a size range for commercial use, the effect of individual hooks would make little difference in the operation. Application of different colors or smells to hooks or baits did not increase its selectivity.

Tester (1959) described preliminary experiments carried out in an aquarium to determine if the fish could select baits smeared with different colors or smells. He concluded, however, that factors of conditioned reflex involved in the repeated experiments lowered applicability of the idea to fish in the wild.

In the case of pole-and-line fishing, it may be theoretically possible for the gear to be selective to some extent, as the fishermen start fishing after they recognize the presence of fish. But actually there can be little selectivity by pole-and-line gear in a field operation. It is true that fishermen have hooks of different sizes and use them at different places and occasions. Yet their intent seems to lie in securing a valuable catch rather than in selecting different sizes of fish. In the case of longline, it would be still more difficult for the line to work selectively. In Japan, a 10-cm longline hook may catch a tuna weighing as little as 10, or as much as 300 kg.

5.2 Net fishing

Generally speaking, a net has more selectivity than line gear in fishing for tuna. This is particularly true of a drift net which is capable of selecting different sizes of fish according to its mesh size. This applies to gill nets which are designed especially for young tunas and skipjack and used in some parts of Southeast Asia. Tangling drift nets for large-size tunas have little selectivity, however.

In case of tuna purse seines, it is again theoretically possible to have them work selectively by the use of different mesh sizes. In a commercial operation, however, it is not practical to use for the sake of selectivity excessively large meshes beyond the critical strength of net twines and fabrics or at the sacrifice of handling ease. In the case of drift nets, Nomura (1961) reported that a fish larger than 10 cm in maximal body girth cannot pass through a 10-cm mesh, but fishermen use a smaller mesh than 10cm because of safety to the net and of handling efficiency. This decision, of course, is dependent on such factors as strength, elongation, elasticity, and fatigue in the net twines. Set-net fishermen in the coastal waters of Japan no longer use specialized gear for catching tunas only. They can usually predict from their experience the size composition of fish which will frequent the fishing grounds so they use the most suitable net twines and mesh sizes.

In regard to mesh selectivity, Miyamoto (1952) reported that Japanese "otshi-ami" employ a large mesh of 60 to 100 cm for the leader net regardless of the size of fish, but a small mesh of 5 to 10 cm for the bag net. The same is true of the leader net and the dead chamber of Sicilian tuna traps. In this connection we observed that small-sized fish which stayed in a large mesh net at night were often seen escaping through meshes at sunrise.

These facts suggest that it is possible to some extent to operate set nets selectively to take fish larger than a certain size. As far as the the protection of young fish is concerned, most of the existing fishing gear for tunas and skipjack — longlines, pole-and-lines, drift nets, and set nets — are passive and conservative, as they must either wait for fish to come or lure fish with bait, or both. On the other hand, purse seines may be regarded an agressive gear which fishermen can operate more positively for tunas than any other type of gear and need neither to wait for fish to come or to lure them with bait.

6 LINES FOR FUTURE WORK

The author wishes to propose here the following subjects to be included in future research programmes pertinent to fishing techniques for tunas and related species:

1) Behaviour of fish as a school
2) Identification of fishing grounds
3) Predation by natural enemies
4) Aids for formation of fishing grounds
5) Electrical fishing

Brief statements may suffice to explain these items.

6.1 Behaviour of fish as a school

In connection with research on the behaviour of fish in the wild, much assistance is expected from such fields as ecology, physiology, and animal psychology. Great encouragement should be given to studies pertaining to this subject.

6.2 Identification of fishing grounds

Selection of a longline fishing ground more or less depends on the fishermen's own experiences and their fishing data. However, effort should be paid to studies of oceanographic factors that influence the occurrence of fishing grounds. Improvement of existing fish finders in regard to accuracy and range is awaited for the use in tuna longline fishing. Accumulation of knowledge for identifying fishing grounds will enormously contribute to expanding the operational potentiality from a stretched single line to a two-dimensional system, and render it possible to design longlines on entirely new principles (Mann 1955, 1957, 1959).

6.3 Predation by natural enemies

In Japan experiments were tried with little success to drive the grampus away from tunas caught on longlines by scaring it with supersonic sound of 30 k.c. If effective means are found for preventing damage by the grampus or for utilizing these obnoxious catches better than we do now, the profits from the longline operation will be greatly increased.

6.4 Aids for formation of fishing grounds

To take advantage of the habit of skipjack for following a drifting object, a float shaped like log or timber can be released into a latent fishing ground. Combining a radio-sonic buoy with the artificial timber and an echo sounder will enable fishermen to find the position of the float and occurrence of fish (Hashimoto et al 1959).

6.5 Electrical fishing

Studies should be continued and expanded in regard to attracting fish by electro-taxis and catching them by electric paralysation (Kreutzer 1951; Meyer-Waarden 1951 and 1955; Dethloff 1959; Kuroki 1955; Miyake and Steiger 1957). Development of scientific techniques for identifying latent longline areas will widen the possibility for commercial application of electric fishing techniques.

Methodological Paper No. 7

STATISTICS OF CATCH AND EFFORT REQUIRED FOR SCIENTIFIC RESEARCH ON THE TUNA FISHERIES

by

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Abstract

Collection and analysis of adequate statistics of catch and effort, together with biological examination of representative samples of the catches, constitute an important means of studying tuna populations quantitatively. International cooperation in these tasks is required because of the wide distribution of the tunas in the high-seas.

Statistics of catch and effort are useful for research of several kinds: (a) measurement of changes in abundance in space and time; (b) investigation of the success of fishermen in locating the best concentrations of tunas; (c) research on population dynamics (relationships of fishing effort to abundance and yield; estimation of sustainable yields and maximum sustainable yield).

For research of types (a) and (b), the collection of statistics for computing catch-per-unit-effort need not be from all voyages of all vessels engaged in the fishery, since it is only required that sufficient observations be available for each time and area stratum employed in the research to provide statistically reliable estimates, but it is necessary that such data be representative and be referrable to fine time and area strata, which can usually be obtained only from logbook records. Research of type (c) is more demanding, requiring not only representative samples to compute catch-per-effort for each tuna population, but also total catch and/or total effort for each population.

It is important that catch and effort statistics be compiled for each kind of fishing gear, and that they be tabulated not only by geographical and time strata, but also according to vessel size, or other characteristics related to the fishing power, so that the catch-per-effort may be calculated in standard units, invariant with changes in the fishing fleets. Methods employed in the collection and analysis of catch and effort data are reviewed.

Means by which adequate collection of catch and effort data, and their exchange among researchers, might be effected are discussed.

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STATISTIQUES DE LA PECHE ET DE L'EFFORT DE PECHE NECESSAIRES A LA RECHERCHE SCIENTIFIQUE SUR LES PECHERIES DE THONS

Résumé

Le rassemblement et l'analyse de données statistiques satisfaisantes sur la pêche et l'effort de pêche, combinés à l'étude biologique d'échantillons représentatifs des prises, jouent un rôle important dans l'étude quantitative des populations de thons. Ces travaux exigent une coopération internationale du fait de la grande dispersion des thons en haute mer.

Les statistiques de la pêche et de l'effort de pêche sont utiles à divers types de recherches: a) mesure des variations, dans le temps et dans l'espace, de l'abondance relative; b) enquêtes sur le succès obtenu par les pêcheurs dans le repérage des meilleures concentrations de thons; c) recherches sur la dynamique des populations (rapport effort de pêche/abondance et rendement; estimation des rendements soutenus et du rendement maximal constant).

Pour les travaux des catégories a et b, les statistiques nécessaires au calcul de la capture par unité d'effort n'ont pas à être obtenues pour toutes les sorties de tous les bâtiments participant à la pêche: il suffit, pour obtenir des estimations statistiques valables, de disposer de suffisamment d'observations pour chacune des strates chronologiques et spatiales utilisées dans les recherches, mais il faut que ces données soient représentatives et puissent être rapportées à des strates bien définies en fonction du temps et de la région de pêche, ce qui requiert généralement le recours aux journaux de pêche. La recherche de la catégorie c exige davantage de travail, car il s'agit non seulement d'obtenir des échantillons représentatifs permettant de calculer pour chaque population thonière la capture par unité d'effort, mais aussi de calculer les captures totales ou l'effort total de pêche pour chaque population.

Il importe que les statistiques relatives à la pêche et à l'effort de pêche soient recueillies pour tous les types d'engins de pêche, et soient mises en tableaux non seulement par strates définies en fonction de la zone géographique et du temps, mais également selon la taille des bateaux ou autres caractéristiques se rapportant à la puissance de pêche, de manière que la capture par unité d'effort puisse être calculée en unités standard, ne dépendant pas des changements survenant dans les flotilles de pêche. L'auteur passe en revue les méthodes employées pour rassembler et analyser les données sur la pêche et l'effort de pêche.

La communication examine les moyens qui permettraient d'assurer de manière satisfaisante la collecte de données sur la pêche et l'effort de pêche et l'échange de ces renseignements entre chercheurs.

ESTADISTICAS DE CAPTURAS Y ESFUERZO NECESITADO PARA LA INVESTIGACION CIENTIFICA EN LA PESQUERIA DEL ATUN

Extracto

El acopio y análisis de estadísticas apropiadas de captura y esfuerzo, junto con el examen biológico de muestras representativas de las capturas, constituye un medio importante de estudiar cuantitativamente las poblaciones de atún. Se precisa la cooperación internacional en estas tareas por razón de la amplia distribución de los atunes en los mares.

Las estadísticas de captura y esfuerzo son útiles para investigaciones de diversos tipos, como son: (a) la medición de las variaciones de la abundancia en el espacio y en el tiempo; (b) la investigación del éxito de los pescadores en la localización de las mayores concentraciones de atunes; (c) los estudios sobre dinámica de la población (relación entre el esfuerzo pesquero y la abundancia y el rendimiento; estimación de los rendimientos sostenibles y máximo rendimiento sostenible).

Para las investigaciones de los tipos (a) y (b), el acopio de estadísticas para calcular las capturas por unidad de esfuerzo, no es necesario que se realice en todas las salidas de todos los barcos que trabajen en la pesquería, ya que solamente se requiere disponer de observaciones suficientes para cada uno de los estratos de tiempo y área empleados en la investigación, con el fin de lograr estimaciones de garantía estadística, pero sí es necesario que tales datos sean representativos y que se refieran a estratos de tiempo y de área reducidos, lo que de ordinario sólo se puede lograr con los datos de los diarios de pesca. Las investigaciones del tipo (c) son más exigentes, y requieren no solamente muestras representativas para calcular la captura por unidad de esfuerzo para cada población de atunes, sino también la captura total o el esfuerzo total, o ambas cosas, para cada una de las poblaciones.

Es importante que se recopilen estadísticas de captura y esfuerzo para cada clase de arte de pesca, y que se tabulen no solamente por estratos geográficos y de tiempo, sino también con arreglo al tamaño del barco u otras características relacionadas con la potencia de pesca, de forma que la captura en función del esfuerzo pueda ser calculada en unidades uniformes, que no varíen con los cambios en las flotas pesqueras. Se pasa revista a los métodos empleados para el acopio y análisis de los datos sobre capturas y esfuerzos.

Se estudian los medios mediante los cuales se podría efectuar una apropiada recolección de datos de capturas y esfuerzo y el intercambio de ellos entre los investigadores.

1 INTRODUCTION

Research on the commercial marine fisheries is essentially concerned with quantitative investigation of the ecology and population dynamics of the fish populations which are the objects of exploitation, including the predator-prey relationships of fishermen and fish. Since the fish are mostly hidden from direct view by the opaque waters of the sea, it is usually not possible to employ techniques of direct observation and enumeration which are widely employed by terrestrial ecologists, and the fishery researchers must rely to a large extent on inferences from samples of the population. We are, however, fortunate in that the operations and results of the commercial fishing fleets provide a widespread sampling scheme for those components of the fish populations of commercial sizes. Adequate collection and analysis of statistics of catch and effort, together with the drawing of representative samples of the catch for determination of size, age, sex, degree of maturity, etc., can thus provide much of the data we require for studying the fish populations quantitatively.

Where a fish population is confined to a relatively small part of the sea, and is exploited by fishermen of only one nation, the establishment of a system for collection of catch and effort data is relatively easy, because it can be accomplished by the research agency or agencies of only one country. The tuna populations, however, characteristically extend over very large ocean areas, and are exploited by fishermen from several different nations. The collection of adequate catch and effort data, and the provision of such data to scientists concerned, requires international cooperation. Unfortunately, such cooperation is not well developed in many regions, in consequence of which much of the data on catch and effort for the tuna fisheries of the world, required for their scientific investigation, are simply not available.

I propose briefly to review the uses to which catch and effort data may be put, the requirements imposed by those uses, the methods of data collection which are currently employed, and improvements which appear to be required in the collection and dissemination of data.

2 USES OF STATISTICS OF CATCH AND EFFORT

2.1 Measurement of changes in abundance in space and time

We require estimates of the abundance of the tunas, stratified in space and time, for a variety of important studies:

(a) For investigation of the distribution of the tunas in relation to environmental factors, such as temperature, food supply, currents, etc., and the seasonal and annual variations therein;

(b) For inferences about the migrations of the tunas. For this purpose, estimates of abundance, suitably stratified in space and time, are used both alone and in combination with information on the size- or age-composition of the catch;

(c) For inferences concerning rates of mortality and year-class strengths (recruitment). This requires comparable successive estimates of abundance for population units, together with information about age composition for the same units.

For these purposes, we do not require complete statistics on catch and effort; we require only to have sufficiently large and representative samples from the time and area strata with which we are concerned to compute the catch-per-unit-of-effort for each stratum. The catch-per-unit-of-effort, of course, does not necessarily provide estimates of true abundance of the tuna in the ocean, which are comparable among strata, since the catch-per-unit-of-effort is affected both by the true abundance of the fish and by their "availability" or "vulnerability" to the fishing gear. The catch-per-unit-of-effort measures, thus, the "apparent abundance", the abundance as the fishermen see it, reflecting the interaction of these factors. For some purposes, the variations in vulnerability may be discounted by suitable averaging processes. It is also sometimes possible to measure variations in vulnerability through tagging experiments (Gulland, MS).

There is an extensive literature on the use of catch-per-effort data for studying the ecology, distribution, and migrations of tunas, only some of which will be referred to here as examples. The Nankai Regional Fisheries Research Laboratory (1959) has compiled extensive samples of logbook records of the Japanese longline fisheries from which have been computed and tabulated catch-per-hundred-hooks, in numbers of fish, by species, by one-degree areas and months, and has also compiled and charted various types of oceanographic data as well as data on size-composition of catches. Similar data have been analyzed by Mimura (1958) for yellowfin tuna in the Indian Ocean to study changes in abundance and to make inferences about population structure and migrations. Yabuta, Anraku and Yukinawa (1958) have made analogous studies of yellowfin in the equatorial Pacific. Similar research has been done on albacore on the south Pacific by Honma and Kamimura (1957), and on bigeye tuna near Japan by Tatsuki et al (1960). Suda (1958) has also examined the estimation of abundance of albacore from catch-per-effort data near Japan.

The Inter-American Tropical Tuna Commission (IATTC) compiles information on total catch and catch-per-effort (tons per day's fishing) for yellowfin and skipjack tuna by one-degree and five-degree areas, by quarterly, monthly and annual time strata in the eastern Pacific (Shimada 1958, Alverson 1959 and 1960, Martin 1962). These data have been studied, together with information on physical, chemical and biological oceanography in the eastern Pacific, to improve our knowledge of space and time variations of abundance of these species in relation to those ecological factors, as reported in several of the Annual Reports of the Commission, and in papers by Brandhorst (1958), Schaefer (1961a), and Blackburn (1960).

Catch localities of albacore have been compiled by the California State Fisheries Laboratory in waters near that State, by one-degree areas, by months, and these data have been used by Clemens (1955, 1961) to investigate the ecology and migrations of that species.

Several of the papers presented by Japanese and American participants at the Pacific Tuna Biology Conference, Honolulu, August 1961, employed catch-per-effort data, together with other kinds of information, to investigate the ecology, migrations, and changes in abundance of various tuna species.

Measurements of abundance of yellowfin tuna, based on catch-per-effort records, over several years in several sub-divisions of the eastern Pacific have been used by Hennemuth (1961) together with age-composition of the catch, to study year-class abundance and mortality rates.

2.2 Investigation of the success of the fishermen in locating the best concentrations of tuna

If one has complete, or nearly complete, records of all fishing operations in a fishing region, stratified by suitably small space and time intervals, the data may be employed to investigate the degree to which the fishermen are successful in locating better-than-average tuna concentrations, to study the variations in this, and their relations to other (ecological) factors. This may be accomplished by computing a "concentration index", which is the ratio of two measures of catch-per-effort, one weighted by the effort employed in each areal stratum and the other not so weighted. This technique has been applied to the yellowfin and skipjack fisheries of the eastern Pacific by Griffiths (1960) and Calkins (1961).

2.3 Research on population dynamics (relationships of fishing effort to abundance and yield; estimation of sustainable yields and maximum sustainable yield)

One of the central problems of many fisheries research agencies is the determination of the effects of fishing on the fish stocks and on the yield which they can sustain, with a view to determining the amount of fishing effort, or the combination of fishing effort and size at first capture, which will be optimum. The optimum is often taken as the maximum sustainable yield, but it can also be regarded as that sustainable harvest which will be optimum under specified economic criteria. The theory and practice of investigations to this end have been discussed in many publications in recent years, some of which are Beverton and Holt (1957), Ricker (1958), Gulland (1961), Schaefer (1954, 1957a, b, 1961b) and Schaefer and Beverton (1962). Two approaches have been followed in such investigations. One of these employs only the data on total catch, total fishing effort, and catch-per-unit-of-effort over a series of years. The other involves information on total effort (fishing mortality rate) and on the vital statistics (age, growth, natural mortality, and recruitment) of the fish population. Both of these approaches, however, require information on total catch and total effort for unit populations of the fish species being studied. For this purpose samples of the fishery for catch-per-effort are not adequate. In addition there must be measurement of the total catch and/or total effort.

The only major tuna fishery for which, to my knowledge, catch and effort statistics adequate for research on its dynamics have been published is that for the tropical tunas (yellowfin and skipjack) of the eastern Pacific Ocean (see papers by Schaefer cited above and other publications of the

IATTC). Adequate data probably also exist for some other tuna fisheries, such as the skipjack fishery near Japan, and the bluefin tuna fishery of the Mediterranean, but they are not available in published form. For other important tuna fisheries, such as those for the tunas of the Indian Ocean, the tunas of the tropical central and western Pacific, and the tropical Atlantic, there exist quite good data on catch-per-effort over a series of years, by suitable time and area strata (some of which have been published), but the vitally needed data on total catch or total effort for these fisheries are not available. In some cases, such as the tropical Atlantic, it might be possible to recover total catch data for past years from the records of the fisheries agencies of the several governments whose fishermen operate there. In other cases, however, such as the Indian Ocean, it seems that the recovery of such data for past years is not possible, and that they are not being collected currently. This is regrettable, since there has been a marked decrease in the abundance of yellowfin tuna (catch-per-hundred-hooks) over the years in the Indian Ocean (Mimura 1958, Tsaruta and Tsunoda 1960) accompanied by a decrease in the size of fish in the catch. This indicates that the fishing effort has measurably affected the yellowfin stocks of the Indian Ocean, but, with the lack of information on total catch, it is impossible to proceed further with the analysis of the dynamics of the fishery to determine its condition in relation to any optimum.

3 REQUIREMENTS

The different uses to which catch and effort statistics may be put impose different requirements respecting the need for completeness and for fineness of time and area stratification.

For the uses listed under (a) and (b) of 2.1, the coverage of the system of collection of statistics for computing catch-per-effort need not be complete, since it is only required that sufficient observations be available for each time and area stratum employed in the research to provide statistically reliable estimates. This type of data is only obtainable from logbook records, except in the case of short-range vessels operating from local bases, where the data may be obtained by interviewers. In either case, the basic data may be obtained by individual days, by geographical areas as small as the navigational precision permits. It is, however, necessary to summarize it by coarser strata for convenience of publication and to provide statistical reliability. Summarization of data by areas of one-degree on a side, and by months, seems adequate for most studies and, indeed, three-month periods are often employed.

For research under item (c) of 2.1, we require, again, only a representative sample of the fishing fleets' operations and results. The catch-per-effort data need to be summed over fairly wide geographical areas encompassing an entire population or sub-population of fish the vital statistics of which are being studied. In time, stratification by quarters is adequate.

Some investigations of the type discussed in 2.2 can be conducted on the basis of only moderately large samples, providing they are representative. For the most sophisticated research of this type, we wish, however, to examine the relationships between the concentration index and the total effort, which requires complete, or near-complete, coverage. The fineness of the time and area stratification will, of course, depend on the particular investigation. In our work in the eastern Pacific, we have employed one-degree areas and quarters of the year.

As noted above, the most demanding research, so far as completeness of statistics is concerned, is that under 2.3. For research on fishery dynamics we require not only representative samples for catch-per-effort for each tuna population with which we are concerned, but we also require total effort and/or total catch for each population. Since we ordinarily do not know in advance the geographical area occupied by each population, it is desirable to collect the data by the finest practicable geographical strata. Where catch-per-effort data are obtained from logbooks or interviews, and are also used for other purposes, we can easily tabulate such records by geographical strata which are certainly finer than the area occupied by a unit population, and regroup them as other evidence indicates to be most realistic. Total effort is usually not obtained directly, since this involves keeping track of the number of unit operations (fishing days, hundreds of hooks fished, etc.) for each of all the vessels in the fishing fleet. It is simpler to obtain records of total catch, from the weights of fish unloaded for example, for rather large areas and time intervals, and compute total effort by dividing total catch by the catch-per-effort obtained from the sample for which detailed logbook or interview records are available.

Where there is one type of gear dominant in a tuna fishery, it is often most practical to employ the catch-per-effort of that gear as the estimator of apparent abundance, and to compute total effort, in equivalent units of that gear, by dividing total catch from all types of gear by the catch-per-effort of the dominant type. Since, however, the dominant type may change radically (as, for example, the recent shift from bait fishing to purse-seining in the eastern tropical Pacific) it is important to collect logbook records, or similar data, from all types of gear, so that direct comparisons may be made of the catching efficiency, or fishing power, of the different types, to provide a basis of directly combining the data from different types of gear where needful.

A related matter which often needs to be taken into account is the differing fishing power of vessels of different sizes. In the Japanese longline fishery this is circumvented by using the catch-per-hundred hooks as the unit of catch-per effort, this being independent of the size or other characteristics of the vessels from which the gear is fished. In the purse-seine and live-bait fisheries, however, the fishing power of vessels is related to their size. To compute the catch-per-effort in units which are invariant with size-composition of the fleet, one needs to tabulate catch and effort data not only by geographical and time strata, but also according to the size, and other characteristics, of the fishing vessels, so that comparisons may be made of the effectiveness of vessels of different characteristics fishing together, and thus derive "efficiency factors" by which the catch-per-effort may be computed in standard units.

Valuable general discussion of the problems mentioned in the foregoing two paragraphs will be found in Beverton and Holt (1957) and in Gulland (1956). Shimada and Schaefer (1956) and Broadhead (1962) illustrate applications to the tuna fishery for the eastern tropical Pacific.

To summarize, it is desirable to collect the following catch and effort data to satisfy the various purposes outlined above:

(a) Total catch, by weight, of each species of tuna, by sea areas at least as small as those occupied by unit populations, by each different kind of fishing gear;

(b) Catch, by weight (or by numbers supplemented by samples of catches to determine average weight) of each species of tuna, and corresponding effort, by areal strata of the order of one degree of latitude by one degree of longitude, and by time strata of the order of a month, for computing catch-per-unit-of-effort, for each type of fishing gear. This need not be for the entire fleet, but should cover a large and representative sample. Where the catch-per-effort is a function of vessel size, or other characteristics, the data need to be further stratified by such characteristics to provide a basis of computing catch-per-effort in standardized units;

(c) Total effort. This may be computed from (a) and (b), or may be gathered directly. In the latter case complete operating records will need to be obtained from every vessel in the fleet.

4 METHODS OF COLLECTION OF DATA

4.1 Composition and characteristics of the fishing fleet

A register of vessels fishing with each kind of gear may be obtained from licence records, or directly from the fleet by continuous canvass. Characteristics, such as tonnage or horsepower, to which fishing power may be related is ordinarily available from licence records or ships registers, or may be obtained by canvass. In the eastern tropical Pacific the fish-carrying capacity, which is related to tonnage (Shimada and Schaefer 1956), is currently employed by the industry, and is most convenient.

4.2 Catch-per-effort

The most useful records for calculating catch-per-effort are obtained from logbooks kept by vessel masters, from which data on each day's operations may be extracted and summarized in the most useful form. In the case of the tuna fisheries conducted by long-range vessels, such records are essential, since they can be tabulated by quite fine geographical and time strata, as noted earlier. It has been our experience, and I believe that of researchers in other countries as well, that the cooperation of vessel masters in keeping good records, is best obtained if the logbooks remain their property, and agents visit them at frequent intervals (each trip so far as possible) and copy the information. Since the long-range tuna fleets consist of relatively few vessels, making long voyages, this requires little manpower.

Where smaller vessels fish in only a relatively limited area of the sea, and make short voyages of only a few days' duration, records of their catch and effort are often most easily obtained by interviews with vessel masters, since masters of such craft often do not keep any written records. Records of companies operating fleets of smaller tuna boats can also often be used in this connection.

Records of the foregoing kinds can be used to compute the catch-per-day-of-actual-fishing (for example in the purse-seine and live-bait fisheries) by fine geographical and temporal strata, or (in the case of the tuna longline fisheries) the catch-per-hook-day.

The catch-per-day's-absence from port, which requires only information on the dates of departure and return of the vessels and their catches on each voyage, is, for long-range vessels, less useful, especially for the purposes of 2.1 and 2.2. Where, however, such vessels operate only within the areas of distribution of single tuna populations, they are useful for the purpose of 2.3. It may, also, be found that there is a close relationship between catch-per-day's-actual-fishing, and catch-per-day's-absence (Shimada and Schaefer 1956), so that the latter may be used to estimate the former for periods when the more detailed logbook records are not available.

It is, of course, important that the catch and effort data be kept by individual vessels, and that their characteristics be determined, so that the data may be ultimately combined into standardized measures of apparent abundance, corrected for differences in fishing power of different vessels, and kinds of gear.

4.3 Total catch

Records of amount of total catch, by species, are usually obtained from statistical returns from companies purchasing the fish at time of unloading. Most countries obtain in this manner quite complete records of total landings of tunas by species. When all the landings in a country are from a fairly restricted area, which encompasses only one population of each tuna species, such returns, without any indication of origin of catches, are adequate for purposes of 2.3. Where, however, long-range tuna vessels land fish from several geographical areas, including more than one population of one or more of the tuna species, it is necessary that the reports also indicate the origin of the catches by geographical strata at least as small as the tuna population units.

The State of California, for example, employs a system of areas of origin (Bureau of Marine Fisheries, 1952) which enables the locality of catch to be recorded either by fairly large areas, or by smaller sub-divisions of these areas, depending on the circumstances. The area of origin, according to this system, is recorded on the sales slip prepared by the buyer of the tuna, a copy of which goes to the State's statistical group. It is essential that, where the sea area may encompass the region inhabited by more than one population of a given tuna species, the records be complete for all landings, unless there is assurance that a sample is truly representative. It is unlikely that a sample of the landings, unless especially designed and drawn, will be properly representative of the geographical distribution of the entire catch. Shimada and Schaefer (1956), for example, demonstrated that in years when a substantial share of landings of yellowfin tuna in California was not reported by area of origin, a greater portion of the unreported catches was from the more distant areas to the south.

Complete data on catches of tunas, by species, by different regions of the sea, are a basic necessity for research on the dynamics of the tuna populations. Since, in many cases, fishermen of several nations are fishing in the same region, it is essential that means be developed for collection and interchange of such statistics.

4.4 Total effort

As indicated earlier, it is usually most convenient to derive total effort from total landings and catch-per-effort. If it is desirable to collect total effort data directly, this involves keeping complete records of the locality of operation of all fishing vessels. This is, apparently, not being done anywhere at the present time, although it is closely approximated for a very large share of the vessels fishing for tropical tunas in the eastern Pacific.

5 EXCHANGE OF DATA AND INFORMATION

5.1 Methods

It is important that adequate catch and effort data not only be collected, but also made available, on a reasonably current basis, to all researchers requiring them. At least two means of accomplishing this can be envisaged:

(a) Data might be compiled and published by each nation for the activities and results of its own fishermen.

This is generally being done now by many of the major fishing nations with respect to total landings. Unfortunately, however, the areas of origin of catches as now published are, in many instances, either completely lacking or not sufficiently precise to be of use in research on the dynamics of the tuna populations; in some cases it is not even possible to ascertain what ocean the fish came from. The research agencies of many countries also publish data on catch-per-effort by small time- and area-strata, but, since these are usually published in conjunction with analyses, there is a considerable time-lag in their availability to other researchers.

Since the number of research workers engaged in the study of tunas is not very large, it might be convenient to establish some acceptable uniform system of compiling data, and exchange them by means of data reports in limited edition.

(b) Data might be assembled from various nations by suitable regional organizations, or even a worldwide organization.

In the eastern Pacific the IATTC has the responsibility of collecting, among other things, catch and effort data for the tropical tunas. It is, however, confronted with some problems in obtaining adequate data from fishermen with bases outside the Americas.

It would be desirable to establish data centers for certain regions of the sea, or even a worldwide data center, to which all nations engaging in the tuna fisheries would send data currently and promptly, in accordance with agreed methods and formats, and from which any interested scientists could obtain them. Such a system has proven very successful for some classes of geophysical and oceanographic (including biological) data, and should be relatively simple to arrange for tuna statistics, if the nations have the will to do so.

5.2 Responsibility

Since the living resources of the high seas are the common property of all mankind, each nation whose fishermen use them has a moral responsibility to keep adequate records on their operations and results, to provide information required for the scientific basis of maintaining the resources in condition to continue to provide food and other materials in optimum quantities to men in the future. It is also of immediate practical importance for the users of the resources to know about their condition, and the effects of the fishing on them, for their own continuing economic benefit.

Paragraph 2 of Article 1 of the Convention on Fishing and Conservation of the Living Resources of the High Seas, adopted by the United Nations Conference on the Law of the Sea, Geneva, 1958, provides that:

> "All States have the duty to adopt, or to co-operate with other States in adopting, such measures for their respective nationals as may be necessary for the conservation of the living resources of the high seas".

Among the most urgently required measures is the collection and exchange of data on catch and effort for such international fisheries as the tuna fisheries, because such data are required to determine when conservation action is required. In only a very few parts of the sea is this responsibility for collection and dissemination of adequate catch and effort data being discharged. It is highly desirable that means be adopted of doing so in all areas of the ocean.

6 RECOMMENDATIONS

One of the most useful things this Meeting could do is to attempt to reach agreement, at least in a general way, on the types of catch and effort statistics which should be compiled, in a uniform manner, by the different nations whose fishermen pursue the tuna fisheries of the high seas, and on the most appropriate means of making such data available to all interested researchers. This would be a first step toward agreements among governments to establishing proper and effective systems of "keeping score" on these valuable resources.

Methodological Paper No. 8

FUTURE LINES OF TUNA RESEARCH, MAINLY IN RELATION TO FISHERIES OCEANOGRAPHY

By

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Abstract

The author discusses future possibilities of tuna fishing and suggests some likely areas for new fishing grounds. He gives a guide as to how future research should be conducted, along both general and oceanographical lines. He shows how oceanography has already helped to give information, for instance on tuna distribution, migration, fluctuations in the stock, recruitment and changes in fishing grounds. If future research is to be successful, it is important that the tuna oceanographer and the biologist work extremely closely together. The author also gives some thought to methods of data collection.

ORIENTATION FUTURE DE LA RECHERCHE SUR LES THONS, PRINCIPALEMENT DU POINT DE VUE DE L'OCEANOGRAPHIE APPLIQUEE AUX PECHES

Résumé

L'auteur examine les possibilités futures de la pêche du thon et mentionne certaines zones susceptibles de renfermer de nouveaux fonds de pêche. Il indique la manière dont la recherche devrait être menée à l'avenir, tant en général que dans le domaine océanographique, et montre les services déjà rendus par l'océanographie en matière de données sur les thons, et notamment sur les points suivants: répartition, migrations, fluctuations du stock, recrutement, et variations dans les lieux de pêche. Le succès de la recherche dépendra dans une grande mesure de l'étroite collaboration qui doit s'établir entre l'océanographe spécialiste du thon et le biologiste. L'auteur aborde également la question des techniques de rassemblement des données.

ORIENTACIONES FUTURAS PARA LA INVESTIGACION DEL ATUN, PRINCIPALMENTE EN RELACION CON LA OCEANOGRAFIA PESQUERA

Extracto

Expone el autor las futuras posibilidades de la pesca del atún y sugiere algunas zonas probables para nuevos caladeros. Da orientaciones para la investigación futura, con ideas de carácter general y oceanográfico. Demuestra que la oceanografía ha contribuido ya a facilitar información; por ejemplo, sobre la distribución y migraciones del atún, las fluctuaciones de su población, reclutamiento y modificaciones en las pesqueras. Para que las investigaciones futuras den resultados satisfactorios, es necesario que oceanógrafos y biólogos especializados en esta especie colaboren íntimamente. El autor dedica también atención a los métodos de acopio de datos.

1 FUTURE PROSPECTS OF TUNA FISHING AREAS

During the past ten years, Japanese longline fishermen have successfully exploited extensive new tuna fishing grounds in the south Pacific, Indian and Atlantic Oceans.

Considering the increasing rate of exploitation, we can expect that certainly within the next ten years the available world tuna fishing areas will be covered by boats from all over the world, including Japan. This means that the potential tuna resources may be exploited almost completely within the next decade, as indicated by the rapid progress in world whaling and trawl fisheries.

Where are the remaining unexploited fishing areas? The north Atlantic offers one possibility for longline fishing; others are the south Atlantic off the Argentine, Brazilian, and west African coasts. Other frontier areas for the tuna fisherman are the south Indian Ocean in southern latitudes near the zone between the Polar Front and the Subtropical Convergence, including the southern part of the Australian Gulf. In the north Pacific Ocean, northeastern waters to the Hawaii Islands are still under-exploited. In the south Pacific, still broader areas are left for the tuna fishermen in the middle and higher latitudes and in the southeastern part off Peru and Chile (southeast to Tahiti Islands).

Future available fishing grounds may be classified into : (a) longline areas producing large-sized tuna; (b) purse-seine areas producing large-and small-sized tuna; and (c) pole and line areas producing medium- and small-sized tuna; the size and abundance of fish vary with oceanographic conditions.

Japanese tuna boats may find it necessary in the near future to improve their method of operation by using as fishing bases the harbors of cooperating countries adjacent to the fishing areas.

All fishermen and fishery scientists wish to enjoy the freedom of the open seas and oceans to conduct their fishing and their studies. They should be willing to cooperate in national and international investigations and surveys to assure the conservation of tuna stocks and permissible maximum utilization. Oceanographic aids may be expected from the pure and applied sciences.

Soon tuna fishermen from many countries will be working in the same fishing areas and will have common interests. An international conference such as this is of value where such matters may be discussed as the size of available resources, the most effective and reasonable plan of utilization, and the regulation of fishing effort including problems of restricting fishing areas and periods in order to secure maximum sustainable yields. Cooperative efforts to encourage local exploitation in virgin fishing areas with potential tuna resources should then be undertaken. Fishermen and fishing scientists should study, by means of field survey and laboratory experiments, the after effects of fishing operations on virgin tuna resources.

Measures to assure the conservation of populations and their maximum allowable utilization should now be considered.

2 FUTURE LINES OF TUNA RESEARCH

In the future, research should be concentrated on several main lines of study:

a) Finding out distribution, concentration and dispersal of tunas;

b) Estimating population size, and evaluating the fishing areas;

c) Developing prediction techniques in the ever-changing seas and oceans, using oceanographic and other scientific data;

d) Developing exploitation techniques for new fishing grounds;

e) Developing rapid communication techniques for fishery, oceanographic and meteorological information for more effective fishing operations and the safety of fishing vessels.

(i) General

The researches of fishery scientists should be concentrated on (a) finding the population size of tunas and its fluctuation in exploited areas; (b) developing techniques for the exploitation of new fishing areas and their utilization. The former objective might be of greater importance in developed countries, and the latter in underdeveloped countries.

In the following decade, when the world's tuna fishing areas are being fully exploited, the fishing countries must study the fluctuation of population size and its prediction, and devise methods of regulation or control in order to achieve maximum sustainable yields. Knowledge gained through fishery oceanography and other sciences should be utilized.

The fisheries for the small-sized tuna might be restricted or controlled for the future conservation of the resources. In particular, the spawning and nursery grounds, especially for tuna larvae and juveniles, should be closely investigated to determine optimum environmental conditions.

The main problem is how to distribute fishing effort most efficiently for the fishing areas, the fishing season and the tuna species while keeping the maximum sustainable yields. It is also essential to develop a background of scientific knowledge. World tuna fishermen should aim at a more scientific and economically rational fishing operation with closer contact with fishery biologists and fishery oceanographers. To this end, they should cooperate with each other and with scientists in exchange of data (fishery, biological, oceanographical and meteorological) and in the collection of specimens. The fishermen, in turn, can profit from information compiled by local, national and international centers of tuna fisheries, for finding favorable fishing localities and for estimating possible catch.

The exploitation of tuna resources is yearly approaching a more critical stage. The organization of a system of collection, compilation, exchange and communication, processing and analysis of materials and data is an urgent need. If tuna stock conservation is not considered, the future prospects of the fisheries may not equal the potential increase that might result from the increase in fishing effort.

Fisheries administration officers and fishery scientists should especially study the economic standards of tuna fishery operation on the basis of the maximum sustainable catch. For an evaluation of the resources from the economic point of view, the total landings for each species should be considered.

Existing conditions on the fishing grounds should be broadcast to the fishermen, oceanographic charts prepared and fisheries catch records and other vital statistics compiled. A five degree grid or, if possible, a one degree grid of latitude and longitude might be adequate for statistics of tuna fisheries on a national and international basis for the Pacific, Atlantic and Indian Oceans.

Fisheries scientists should supply directories to tuna fishermen, with maps of potential resources, productivity, changing state of currents and water masses, as well as weather conditions and, lastly, a prediction of fish abundance and availability. The rapid communication of information by radiotelegraph and facsimile is a further aid to successful fishing.

(ii) Oceanographical

There is need on a world-wide basis for more advanced information on the distribution of the different species of tuna and their association with oceanographic structures such as oceanic fronts (Siome and Siozakai), upwelling, ridging, doming eddies, and so on.

What oceanographic structures and their elements should be observed? How can the data be collected and utilized? How can a system of observation and collection of data, and eventually of communication, be established and coordinated on local, national and international levels?

Past experience shows that the exploitation of new tuna fishing grounds and the carrying out of extensive exploratory fishing operations are materially aided by oceanographic charts and information, as well as by equipment such as BT, echosounders, fish finders, etc. Fishery-oceanography charts, which bear closely on the distribution of tunas, are useful for evaluating the localities of concentration and, therefore, for finding the most favorable fishing grounds.

Analysis of the trend of oceanographic patterns may give the prediction indices, using interrelationship formulae including the biological features of the environment. Certain water-mass characteristics, identified by the conservative T-S relationship and the discriminant function analysis for the upper 200 to 300 m layer depths, may be related to the distribution of tunas. Variation and distribution of water temperature under the influence of the sea-atmosphere interaction system are important for predicting variations in their abundance and availability.

Cyclic changes of oceanographic conditions and of tuna abundance seem to be connected, and this could be considered for a potential prediction technique. A reciprocal relationship in water temperature on the west and east sides of the Pacific Ocean has been noted in data from monitoring stations and from offshore oceanographic observations.

The possible influence upon the size of tuna populations of the waters of the Gulf Stream, and of the Kuroshio, East Australian, Brazil, Somali, Mozambique and Agulhas Currents, as well as of the California, Canary and Guinea, Peru, Benguela and West Australian Currents, should be studied by means of international cooperation. Similarly, the possible influence of the waters of the Equatorial Under Current and Equatorial Counter Currents, and of the North and South Equatorial Currents, should be closely studied.

3 WHAT HAS BEEN ACCOMPLISHED BY TUNA OCEANOGRAPHY

"Tuna water" constitutes the optimum oceanographic conditions for tuna. Optimum water temperature for each tuna species has been reasonably well established (California Cooperative Oceanic Fisheries Investigations, Pacific Tuna Biology Conference 1962).

The boundaries of water masses and currents, which serve as environmental barriers for tuna species, have been extensively determined in the world oceans. Local tuna aggregations are associated with the surface indication of oceanic fronts or Siome, i. e. current-rips, or tide-rips, slicks and discolored bands, etc., marking the boundary of water masses. These phenomena indicate a convergence or front which results in accumulation of flotsam. Flocks of sea birds, drift wood or flotsam, whales and sharks are all recognized as indicators of tuna schools and tuna fishing grounds.

The changing fronts of oceanographic structure have a bearing on the migrations of tunas, on the fluctuation of the stocks, and on the reproductive potential or recruitment of tunas. The equatorial tuna fishing areas in relation to the equatorial upwelling, Equatorial Under Current and Equatorial Counter Current, lines of divergence and convergence have been studied successfully. The Polar fronts, Subtropical Convergences and the coastal fronts influence the distribution of tunas and biota related to tunas.

In tropical waters, it has been found that ridging and doming of the cold subsurface layer, as indicated by the thermocline typography, affects productivity and may cause a concentration of tunas. Other possible factors are coastal upwelling and vertical mixing.

Eddies associated with ridges and islands, or occurring in the open ocean, may be accompanied by upwelling and form areas of favorable fishing. Concentrations of skipjack are associated with the complex system of eddies downstream from the Hawaiian Islands chain and from the Idu-Ogasawara Islands chain. Island reefs and banks also influence the concentration of tunas and their migration routes. It is generally recognized that tunas are much more abundant near islands than in the open sea.

In the Kuroshio anomalous years, tunas aggregate around upwelled cold waters and migrate farther north than normal. In the so-called El Niño years, the tropical tunas are apparently much more scattered than in non-El Niño years, and also occur in abundance farther to the south than normal.

Forecasts of the annual yield of tunas are based on the intensity or development of cold and warm currents in the southern and northern extensions of their range. Warming following other favorable conditions of productivity seems to cause a rising trend in fish abundance. In northern waters tuna catches below or above normal correspond to below or above average temperatures. Thus, potential availability could be predicted from the temperature anomaly during the months ahead.

The recovery rate of tagged tuna or the mortality rate of larva tuna may vary widely depending on the water temperature.

Tunas conduct feeding migrations in search of abundant food organisms, and spawning migrations seeking favorable grounds for reproduction. Recent tagging experiments, hook recovery and racial studies on tuna populations have given supporting evidence of the trans-oceanic long-range migration and of the mixed or linked (interrelated) populations in the broader areas of the oceans.

Non-seasonal migrations occur, corresponding to the fluctuation of oceanic currents, especially of cold and warm water intrusions. Historical records indicate that cyclic, long-term fluctuations in tuna abundance correspond to fluctuations in environmental conditions, i.e., climate, warm and cold periods of intrusion, and sun-spot activity. The effect of the environment on the population size of tunas is one of the most important problems to solve if we are to achieve effective conservation and utilization of tuna stocks.

The reproductive potential varies according to environmental conditions affecting the transport, dispersal and distribution of the eggs, larvae, and juvenile tunas. Scientists engaged in fishery oceanography and fishery biology (including population dynamics) should cooperate closely on this problem.

Good feeding grounds for tunas depend on an abundance of small prey-fish as well as special hydrographic conditions. A good correspondence exists between the abundance of tunas and the production of organisms, lower in the food chain, related to the enrichment of the euphotic zone by nutrient rich water from deeper layers. Tunas are encountered in greatest abundance in regions where there is a high standing crop of zooplankton near the oceanic fronts.

Changes in fishing grounds and in the size of apparent tuna resources can be related to the expansion and contraction of the highly-saline water masses in the middle latitudes and of the low-saline water masses near the American Continent and the Equator. Rich or poor skipjack catches occur in the Hawaiian fishery depending on the location of the California Current Extension of lower salinity and higher temperature, and the Kuroshio Current Extension of higher salinity and lower temperature.

A shallow thermocline acts as a physical barrier limiting the vertical migrations of tunas. Larvae tunas occurring just above the thermocline interface may suffer high mortality because of oxygen deficiency.

4 TUNA FISHERIES FORECASTING

The increasing attention given recently to the interaction between the tuna fisheries and oceanographical fields of research, not only for the location and investigation of new fisheries resources but particularly for the estimation and prediction of the size and distribution of tuna resources, is noteworthy.

A systematic combination of the biological, hydrographical, meteorological and statistical sciences has furthered our knowledge of biological productivity, of the habits of fish stocks and the nature of the fisheries themselves.

Our ultimate aim is the prediction and control of population abundance (total yield), prediction of distribution and concentration or localization of fish-stocks (location of favorable fishing grounds), development of fishing operations with maximum efficiency and safety, and utilization of available knowledge in oceanography and meteorology.

In the past there was a wide gap between fishery biology and fishery oceanography. Oceanographers were primarily interested in the collection, description and analysis of data in sufficient mass to understand and predict sea conditions, and secondarily in how certain species or population of fish reacted to environmental factors. Fishery biologists, on the other hand, were interested in regulating the fishery on the basis of population dynamics, and conducted their studies on biological aspects (taxonomic variation, distribution, concentration, migration, growth, population size, survival, and mortality) independent of oceanography. At present, concerning reproductive potential or recruitment, rate of survival or rate of mortality, the fishery biologist seeks the effect of environmental factors on tuna populations.

Now is the time to bring together fishery biology and fishery oceanography and to amalgamate the parallelisms in these disciplines. Studies in fishery oceanography in relation to all problems of fisheries biology should be extensively encouraged.

The joining of tuna oceanography, tuna biology including fish pathology, marine biology, and experimental biology, in addition to instrument development, presents an urgent problem.

Tuna fisheries oceanography should aim to study the changing seas and determine the biological consequences of changes at various trophic levels as affecting tunas, and to proceed with the experimental determination of environmental requirements critical for survival of various organisms, and particularly larval tunas.

Annual increase in a tuna population is a function of population size and environmental capacity. The environmental capacity which is cyclic in nature changes greatly year by year and affects recruitment and mortality, hence the annual yield. Under the changing environment, the effective birth-rate varies widely year by year, apparently apart from the size of spawning stock. Also the year class strength, computed from the data of age composition, is subject to change.

We must study a specified water mass in respect to tuna spawning, a water mass capable of producing enough food for maintenance of metabolic activity and growth of larvae, juveniles (nursery grounds) and adults (feeding grounds). We must discriminate between water masses in respect to the success or failure of year classes and to satisfactory conditions for the feeding and spawning migrations of tunas and their availability.

Studies in population dynamics tell us how a fish population in a steady environment reacts theoretically to fishing, but not in a changing environment. Fishery oceanography can estimate the relative strength of a fish population and its trends on the basis of environmental conditions. These sciences must closely cooperate in the future. Fishery science without fishery oceanography would be unable to predict population abundance in a changing environment.

Environment of a population is composed of fixed geographical and geological conditions as its frame on one hand, and of various hydrographical (physical, chemical), biological and meteorological conditions on the other. The ocean is characterized by generally unsteady, transient conditions. To study it necessitates long continued and well-designed surveys which are expensive and time-consuming but without which we cannot hope to solve the problems.

The varying influx or intrustion of cold or warm waters, of coastal, or oceanic waters, is the key to many fluctuations in fish abundance. Plankton organisms are useful indicators of hydrographic conditions. The warming or cooling of the sea, rise or fall of plankton, variations in abundance of young fish, and the reduced or increased renewal of nutrients or level productivity (C^{14} method, etc.) are particularly worthy of investigation.

The tropical ocean is a two-layer system of persistent stability with the upper mixed-layer separated by a strong thermocline (pycnocline) from the lower layer. Variations in the productivity or fertility of the tropical ocean is dependent upon changes in the physical processes of upwelling in horizontal currents, vertical mixing with the lower layer, and the prevailing winds.

Fertilization of tuna spawning grounds and nursery grounds by intrusion of cold water from higher latitudes and the equatorial upwelling from deeper layers contribute to the production of tuna populations. The waters in the tropical latitudes become more fertile during the southward intrusion of cold water, which in turn might have an after-effect upon the year-class strength of tunas. The progressive northward extension of tuna distribution occurs together with a favorable environment. Correlations have been obtained between the tuna catch and solar activity (sunspot number), with the highest correlation in years of extreme temperature.

A prediction technique should be developed in the following order. We should first study the atmospheric pressure field, next the changing wind field, and third the changing current field (through wind stress). The upper ocean and lower atmosphere are a closely inter-acting system affecting each other intimately and in turn affected by the processes in the deeper ocean and the upper atmosphere.

The processes whereby the surface layer is refertilized with nutrient salts from below appear to be either directly wind-produced (e.g., wind-stirring and coastal upwelling) or secondary effects of wind-driven circulation (e.g., ridging or doming etc). Thus, changes in the wind field lead eventually to changes in the success of tuna fisheries through the change of oceanographic conditions.

We can proceed to the forecast of the changes in abundance, distribution and availability of tunas, first tentatively in a statistical way, and next successively improve the methods from a fundamental understanding of the interplay of the pertinent atmospheric, oceanic and biospheric processes

5 METHODS OF DATA COLLECTION

We must devise cheap and satisfactory methods for the collection of data with the proper synopticity and continuity. Semi-continuous observations from merchant vessels and fishing vessels can be obtained at modest expense and utilized in addition to the data from shore and island bases and from research vessels. We need unmanned, automatic data collecting devices to make continuous subsurface observations at several key stations (at least to 200 or 300 m depth), operated for both short- and long-term periods.

Synoptic fishery oceanographic charts, giving the distribution of tuna stocks, should be produced as directories or manuals for fishing operations.

Fishery statistics maps should be drawn for each ocean area. They should be based on the hook-rate or catch-per-unit-of-effort for each five degree grid for Class A commercial boats, and for a one degree grid for Class B semi-commercial boats and Class C boats (research and training vessels). The basic principle of open fishing grounds and international cooperation should be retained.

The proposed organization for the collection of data, its processing and analysis, communication and exchange, is as follows:

Local fisheries center....... mainly for A boats,

National fisheries center.... for A, B and C boats, including the special B boats of governmental and selected commercial concerns,

International fisheries center.. assemble the data of the selected boats.

All registered tuna boats should be requested to report at noon daily, through radio-telegraphy, their position, the water temperature, number of tuna boats sighted, catch (tons per day), the catch condition (rich, medium, poor), the quality of the tuna flesh, and the presence of sharks or killer whales (natural enemy of tunas). The analysis of compiled data should be submitted to each fisheries agency (including research laboratory) and specially selected institutes.

The international center should undertake coordinated surveys and investigations. Its task is to compile the gathered materials, combine with other sources, analyze, and report the results. A uniform format for data collection should be established. The exchange of the compiled information of macroscopic sea and fisheries conditions through facsimile is recommended.

6 CONCLUSION

Future lines of tuna research are needed as follows:

a) Broad surveys of the circulation, of the distribution of biological, physical and chemical properties, and of the distribution, composition and abundance of tunas.

b) More detailed fishery oceanographic, and experimental studies of some smaller scale features which are important to tuna ecology and reproductive potential.

c) Particular studies such as fishery oceanography concerning the effects of thermal domes, islands, banks, temporal variations, monsoon and trade winds.

d) Analysis of the year-class strength of tunas in relation to continuously collected data (statistical, biological and oceanographical).

e) Ecological and physiological changes of tunas in the course of migration or while on the spawning grounds, nursery grounds, or fishing grounds, in response to the oceanographic fluctuations.

f) Development of related instrumentation and methods for the exploitation of new fishing grounds (e.g., underwater observation chamber on the Charles H. Gilbert, specially designed BT, salinometer, current meter, somewhat like the GEK, for tuna fishermen's use, aerial scouting of tuna schools, specially designed fish finder including sonar for tunas, automatically recording buoys and improved communication systems).

g) Solution to the problem of damage to tunas by sharks and killer-whales.

h) Studies of the long-term fluctuations and interrelated mechanisms of oceanic climate and tuna populations.

i) Produce improved fishery-oceanographic charts for tuna vessels (if possible, include weather charts).

j) Devise effective measures to prevent adverse effects of overfishing.

k) Establish reasonably restricted areas and seasons for tuna fishing based on the needs of the fish for spawning and nursery grounds.

l) Fishery biological and oceanographical studies to estimate, evaluate and conserve tuna populations, in order to secure the maximum sustainable catch.

m) Permanent organization for scientific research and a conference (committee) for world tuna fisheries.

Methodological Paper No. 9

WORLD-WIDE TUNA RESEARCH PLANNING

By

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Abstract

The production of tuna from the world's oceans has approximately doubled in the past ten years and gives every sign of doubling again in the next ten. This has led to a considerable augmentation of research on the tunas and their fishery, and has resulted in six major national and regional conferences and symposia on these subjects in the past four years. Contemporaneously a vast expansion has been taking place in other ocean research and its organization internationally.

The further expansion of the tuna fishery will create new stresses of a scientific, diplomatic, economic and social nature in the international field which are capable of being much relieved and often eliminated by the increased knowledge and understanding that competent research can bring. Former regional symposia have contributed much to forward planning of such research through resolutions and recommendations. This Conference will develop more. It is not anticipated that the actions sc recommended will produce much result unless the Conference undertakes some means to assure their implementation.

Accordingly, it is recommended that this Conference create a continuing Committee on Implementation to see that its resolutions and recommendations are brought to the attention of the appropriate bodies and agencies with a view to their being put into effect.

L'ORGANISATION DE LA RECHERCHE MONDIALE SUR LE THON

Résumé

La production du thon des océans à travers le monde a environ doublé au cours des dix dernières années et tout indique qu'elle se redoublera de nouveau dans les dix années à venir. Ce phénomène a suscité un accroissement de la recherche sur le thon et sa pêche et il en est résulté au cours des quatre dernières années six congrès majeurs, nationaux et régionaux, sur ces sujets, ainsi que des symposiums. En même temps ont eu lieu de grands développements dans d'autres aspects de la recherche océanographique et son organisation internationale.

Le développement accru de la pêche du thon créera sur le plan international de nouvelles tensions d'ordre scientifique, diplomatique, économique et social susceptibles d'être beaucoup allégées et souvent supprimées par l'élargissement des connaissances et de la compréhension que peut y apporter une recherche compétente. Par des résolutions et des recommandations des symposiums précédents ont beaucoup contribué à l'organisation de futures recherches de ce genre. Ce congres en promouvera d'autres. On ne prévoit pas que les actions ainsi recommandées puissent aboutir à quelque résultat à moins que le Congrès prenne certaines mesures pour en assurer la réalisation.

En conséquence, on recommande que ce Congrès crée un Comité permanent de Réalisation afin d'assurer que ses résolutions et ses recommandations soient portées à l'attention des groupes et des agences appropriés en vue de leur mise à exécution.

PLAN MUNDIAL PARA LA INVESTIGACION DEL ATUN

Extracto

La producción de atún en todos los océanos se ha duplicado en los últimos diez años y presenta señales de incrementarse nuevamente en la misma proporción en los próximos diez años. Como consecuencia de esto se han intensificado las investigaciones sobre el atún y su pesca, lo que ha dado lugar en los últimos cuatro años a séis importantes conferencias y congresos nacionales y regionales. Al mismo tiempo se ha obtenido una notable expansión en otras investigaciones oceanográficas y en las correspondientes organizaciones internacionales.

La expansión de la pesca del atún creará en el futuro nuevas tensiones de naturaleza científica, diplomática, económica y social en el campo internacional; lo que podría atenuarse e incluso llegar a eliminarse mediante el aumento de conocimientos y comprensión mutua, lo cual se podrá conseguir gracias a la investigación. Los congresos regionales que se han venido celebrando, han contribuído mucho en el avance y el planeamiento de tales investigaciones por medio de convenientes resoluciones y recomendaciones. Esta Conferencia producirá más ventajas aún. Las acciones recomendadas en esta Conferencia surtirán el efecto propuesto siempre que dicha Conferencia disponga de algún medio o mecanismo que asegure que tales normas se lleven a la práctica.

En efecto, se recomienda en esta Conferencia que se cree un Comité Ejecutivo permanente, encargado de vigilar por el cumplimiento de sus resoluciones y recomendaciones, con el objeto de que éstas sean atendidas por las correspondientes agencias e individuos, y sean puestas en vigor.

1 INTRODUCTION

In the years since 1945 the tuna producing industry and the ocean research associated with it have been growing at a rapid rate. This growth has been proceeding at the same time that deep sea ocean research not necessarily related to tuna has been expanding at a similarly rapid rate, international and intergovernmental organization in related matters has been going forward, and the entire role of science and technology in mankind's life and government has been changing. To a casual observer the rates of changes in all of these fields of human endeavor do not appear to be slackening and at least the volume effect they produce is substantial, if not at times startling.

World-wide tuna production statistics prior to and during this period have not been sufficiently precise to refer to except in general terms. These have been discussed in another connection earlier this year (Chapman, 1962). One may say quite roughly that the world tuna production in 1950 was about 400,000 tons and in 1960 was quite close to 800,000 tons. It appears to be continuing to grow. In the United States the market for canned tuna has a little more than doubled every ten years for the past fifty years and is still increasing at about the same rate. Thus one may hazard the guess that the world tuna market will require about 1,500,000 tons of tuna, round weight, in 1970. From the standpoint of science, government, and industry it would at least be prudent for us to be planning our activities as if this were going to be approximately true. An increase in market and use in this range will put substantial added stresses on the stocks of tuna and the research efforts associated therewith.

The greatly increased tuna production in this recent span of years has brought material changes in the United States and in the Americas in the organization and extent of ocean research directly associated with the tuna resource, or stimulated therefrom. Prior to 1945 very little tuna research was done in the United States except by the California Department of Fish and Game. To this in the post-war years has been added the Pacific Oceanic Fisheries Investigations in the Central Pacific which have become the Bureau of Commercial Fisheries Biological Laboratory in Honolulu; directly growing out of this has been the Bureau of Commercial Fisheries Biological Laboratory at Stanford, where Dr. Sette and his staff are looking at relations of air, ocean and fisheries in the entire Pacific north of 20°S. latitude; then came the Scripps Tuna Oceanography Research program of the Scripps Institution of Oceanography, supported by the Bureau of Commercial Fisheries; lastly has come the Bureau of Commercial Fisheries Laboratory at San Diego, where Mr. Howard and his staff are rapidly beginning to make their weight felt. Starting only shortly after POFI, in 1950, the Inter-American Tropical Tuna Commission staff under the direction of Dr. Schaefer, have contributed mightily to knowledge and understanding of the tropical tunas of the Eastern Pacific, the ocean where they live, and the fishery upon them.

The enormous expansion of the Japanese tuna industry to a world wide level in the past ten years especially has brought a similar stimulation to tuna oceanic research in that nation and in the whole tropical and temperate world ocean. Unfortunately, the author is not sufficiently well informed as to even detail these research growths in Japan as roughly as was done above in the case of the United States. Tuna ocean research has also been increasing in Europe, Africa, India and Australia among others.

The International Geophysical Year in the late 1950's resulted in a considerable stimulation of deep sea oceanic research on a world wide basis. Growing out of this the Scientific Committee on Oceanic Research of the International Council of Scientific Unions, and the various National Committees associated with it, have continued to stimulate the growth of international oceanography in a vigorous manner. Out of this activity has arisen the massive International Indian Ocean Expedition in which scientists of thirty nations are involved. Proceeding, an Office of Oceanography was organized last year in UNESCO. Finally last autumn was held the organizational meeting of the Intergovernmental Oceanographic Commission.

In the series of resolutions resulting from the inaugural meeting of IOC (UNESCO/NS/176, Paris, 1 February, 1962) resolution three, in part, recommended to the forty-odd member nations eleven massive international oceanographic programs covering most of the world ocean. Two of these were particularly concerned with tuna in the tropical Atlantic and in the Eastern Tropical Pacific Ocean. Two others, concerned with the Gulf of Mexico and Caribbean and the Australian-Asiatic sea areas, had a considerable tuna component.

IOC also requested its Secretariat to initiate the preparation of a comprehensive program for world ocean study through the most effective means at its disposal.

2 PRECEDING TUNA CONFERENCES

In the past four years a series of conferences has been held at various places in the world concerned with the tuna and their fisheries almost exclusively. These have been:

1. United States - Japan Conference on Trade in Tuna held in Tokyo, October 1959.
2. Symposium on Thunnidae, held under the auspices of the Commission for Technical Co-operation in Africa South of the Sahara, in Dakar, Senegal, December, 1960.
3. Pacific Tuna Biology Conference, held under the auspices of the Bureau of Commercial Fisheries Biological Laboratory at Honolulu, in Honolulu, Hawaii, in August, 1961.

4. Government - Industry tuna meeting, held under the auspices of the California Area Office, Bureau of Commercial Fisheries, at the Scripps Institution of Oceanography, La Jolla, California, January, 1962.
5. Symposium on Scombroid Fishes, held under the auspices of the Marine Biological Association of India, at Mandapam Camp, South India, January, 1962, and this,
6. World Scientific Meeting on the Biology of Tunas and Related Species, held under the auspices of the Food and Agriculture Organization of the United Nations, La Jolla, California, July, 1962.

The author has had the unusual opportunity of being the only person in the world to participate in all of these last noted six meetings on tuna and has also been priveledged to attend the last two Biennial FAO Conferences in Rome, the IOC Conference in Paris, and some meetings of SCOR. It is on the basis of material received at these meetings and travel in about thirty-five countries on tuna and ocean research business in the past five years that the following observations on World-Wide Tuna Research Planning are made.

To begin with one may say that as a result of all of these goings on: (1) ocean researchers are beginning to look at the world ocean as one entity; (2) tuna researchers among them are beginning to look at tuna problems on a unitary world wide basis; (3) tuna producing firms are beginning to look to the whole world ocean as a unit for their supplies of raw material; and (4) tuna processing and marketing firms are beginning to think in terms of a rather fluid, interrelated world-wide tuna market. Thus it is appropriate that this conference has been called on a world-wide basis to examine problems arising particularly out of (2) above, but not unrelated to these other trends.

The several primarily tuna conferences noted above have produced a formidable mass of reports analysing recent findings by tuna researchers, outlining problems that still await solution, and in several instances making recommendations as to what further should be done. A recounting of some of these things may be in order.

3 POPULATION DYNAMICS

3.1 Tuna speciation

The first basis one must have in order to consider tuna problems is a common terminology so that one can know what sort of tuna is being talked or written about. Heretofore this has not been available either in terms of scientific or common usage. It was a material inconvenience at the Dakar Symposium, for instance, that when the European scientists were talking about albacore they were speaking of a different species of fish than were their American and some African colleagues. It is a trade inconvenience that two not very closely related species of tuna in the Indian Ocean are referred to as northern bluefin in one case and southern bluefin in the other. The scientific terminology of tunas has been indescribably mixed up until the last two or three years, to the extent that scientists in scientific meetings have ordinarily chosen to use common names even though there has been no fully accepted list of common names.

This confusion has arisen from three basic causes (1) the big tunas are too large to ship or store conveniently with the sort of economic resources available to ichthyologists,--- (2) funds available to ichthyologists have not permitted any of them to go to different parts of the world and examine these big fish in a critically comparative manner where they were and (3) several, if not all, the big species of tuna are world wide in their distribution with minor structural differences in different areas. In essence the tuna have been more migratory than the scientists, the latter have described what of the former they saw in the area available to them, and no ichthyologist has been able to study all the tunas from all the major points of their distribution.

Much new light was thrown on this subject at the Honolulu Conference last year by the papers presented by Collette (1961), and Roedel and Fitch (1961), and particularly by Gibbs and Royce during the course of discussions. To relieve the difficulties noted above it was recommended that the subject be reviewed thoroughly for this conference, and Dr. Hiroshi Nakamura kindly offered cooperation in collecting specimens of tuna from the far flung Japanese fishing operations in nearly all sectors of the world ocean.

Much further progress has been made in the background papers prepared for the present meeting. In particular Collette and Gibbs (Methodological Paper 1A) have set out clearly the status of the problem and what further needs to be done to resolve it.

Certainly at the very first instance it is necessary to finally straighten out the taxonomy of the tunas and their close relatives in a definitive manner. This can only be done by getting adequate specimens and competent interested ichthyologists together with time for the latter to work on the former. Nobody has yet been able to afford to do this on a world-wide basis. The money to permit this must be found.

3.2 Sub-populations of tuna species

As has been noted throughout these symposia and conference it is not possible to rationally attack the problem of population dynamics, the effect of a fishery upon a population of tuna, determine when conservation regulations are necessary, or to devise sensible conservation regulations unless one can first determine with reasonable accuracy the geographic range of a reasonably homogeneous population of one species of tuna.

That it will be necessary to protect some populations of tuna by conservation regulations as the fishing pressure mounts above the million ton per year level seems to go without saying. The Inter-American Tropical Tuna Commission has already given notice that the point of maximum sustainable production has been exceeded by the fishery for yellowfin tuna in the Eastern Pacific Ocean. Even in this instance, the population of tunas most thoroughly studied from the standpoint of population dynamics, it is not certain that the fishery is working on a single homogeneous population. (Schaefer, 1961).

With respect to other populations of yellowfin tuna the situation is at least complex. Whether those of the Central and Western Pacific represent a single intermixing population or a number of independent or semi-independent populations is not clear (Hiyama and Kurogane, 1961; Royce, 1961; Nakamura 1961; Kamimura and Honma, 1962). What is the situation with yellowfin tuna in other oceans or between the Atlantic and Indian Oceans around the Cape of Good Hope, is hardly suggested as yet. There is already continuing and growing worry about declines in catch per unit of effort in long-line fishing all over the world, and really nothing can be said about the relation of this to overfishing in the present state of knowledge.

That some populations of some species of tuna inhabit geographic ranges of unexpected extent is indicated in some instances and suggested for others by recent tag recoveries. For instance, the evidence seems reasonably solid that the albacore of the North Pacific form one homogeneous, quite fully intermixing population (Otsu and Uchida, 1961). The recovery of bluefin tuna marked along the north American coast in the fishery of the Bay of Biscay and off Norway (Mather 1960; 1962 and M.S.) indicate a degree of intermixing of the North Atlantic bluefin but yield little information as to the degree of intermixing as yet. The recovery of a single skipjack tuna tagged in the Eastern Pacific in the Hawaiian fishery merely gives a tantalizing clue in respect of the central Pacific populations of this enigmatic species (Samson, 1962).

Some illustrative problems of an international character arising from this lack of knowledge upon which little information has yet been gained are these:

(1) Does the rather heavy fishery for larger Indomaguro by Japanese fishermen south of the Lesser Sunda Islands work on the same stock of bluefin tuna as is fished in smaller sizes off the coast of southern and southwest Australia (Mimura, 1961)?

(2) Does the fishery for albacore off Chile work on the same population as the long-line fishery south of Samoa and to New Zealand and Australia as might be suggested by the work on North Pacific albacore?

(3) Are the bluefin populations of the Western Atlantic contributory to those of the Eastern Atlantic?

Dozens of such problems which are presently of only scientific interest will become of high international diplomatic concern as the fisheries for tuna in the world ocean continue to increase. For instance substantially nothing is known about the population structure of the yellowfins already supporting a large multi-nation fishery in the tropical Atlantic. Concern over this problem looms large in the reports and recommendations of all the recent tuna symposia and conference noted above (Marr, 1962; Information Paper No. 3, 1962).

The Dakar Symposium recommendations referred to the necessity for similarity of methodology in the morphometric attack on this problem. The Pacific Tuna Biology Conference noted the still nascent conclusions from serology, biochemistry and immunology and the need not only for further work on methodology but the desirability of attacking one particular problem from the standpoint of biochemical, morphological and serological methods. The Mandapam Camp Symposium recommended that a system of defining homogeneous stocks of different tuna species be extended to a thorough coverage of the tunas and bill fishes of the Indian Ocean and suggested that the collection, care and shipment of the required samples might be an appropriate function for the Centre of Biological Works to be established at Cochin in connection with the Indian Ocean Expedition.

It seems obvious that this sub-population study is an international problem of serious magnitude, that it is not being attacked on a scale remotely resembling necessities, and that there is no national or international group sponsoring, or equipped to sponsor, research of this nature on the scale that is required.

3.3 Statistics of catch and effort

World tuna catch statistics leave much to be desired from every level of use to which they may be put, whether for trade, scientific or conservation purposes.

The only agency presently attempting to publish regularly the statistics of tuna catch on a world wide basis for any purpose is the Fisheries Division of FAO. It is questionable whether the totals thus arrived at are closer than ten or fifteen percent of being accurate. The table of catch statistics for all species of scombroid fishes for 1960 contains about 2,244,000 short tons of all these sorts of fishes of which 158,000 tons can only be listed as "various" and could not even be split into large groupings such as bill fishes, tunas, cutlass fishes, etc., much less into individual species of tuna. In quite a number of cases it is well known that the figures listed as tuna in these tables are no better than informed guesses, and sometimes the information is not very extensive. For instance it has been estimated for some years that 20,000 tons of skipjack are produced each year in the Maldive Islands. The author has not been able to find anyone who is sure of that figure within a fifty percent range of accuracy.

This is certainly not the fault of the Statistics Section of FAO's Fisheries Division which has been making especially strenuous efforts to perfect its statistics of tuna catch. The fault lies squarely with the member countries and the lack of any single agency having this responsibility in respect of tuna. It is almost a general rule that countries in the tropics do not have sophisticated systems of fish statistic recording and it may be a good many years before this will be rectified. Some of the more sophisticated fishing countries, however, also still group all the tuna catches of whatever species together in one lump, which may also include other sorts of fish as well.

If, as seems certain, the local catch and use of tuna in the developing countries of the tropics and sub-tropics increases sharply during the next ten years it will become an increasingly hopeless task to get even a roughest estimate of total annual tuna production in the world for even historical purposes.

Such statistics as FAO is able to gather together now are so badly delayed in their presentation that they are of little use for trade purposes and since their quality is too bad for most biological purposes the resultant statistics serve mostly as historical estimates useful to others than those concerned directly with the tuna industry or the tuna resource. Again this is no fault of the overburdened staff of FAO's Fishery Statistics Section. The member countries will simply not send their statistics in more promptly, and as it is the staff has to spend entirely too much of its time writing prodding letters to member countries to send in any statistics at all.

When one comes further to a desire to find out what amount of what kind of tuna is caught in a particular ocean, much less a section thereof, one can make only the crudest estimates now about most of the world ocean based on all published statistics of any agency.

If one is to study the population dynamics of any particular stock of tuna and its relations to the fishing effort put upon it one must know not only the total catch of tuna from that stock but also the amount of effort used in capturing it. We simply have no other reasonably effective way to measure the effect of fishing effort on the abundance of the fish. These matters have been more fully discussed by Schaefer, Methodological Paper No. 7.

It may be said that with very few exceptions, such as the statistics of tuna catch in the eastern tropical Pacific where the Inter-American Tropical Tuna Commission is active, no statistics of tuna catch suitable for use in population dynamics work are being kept. In the multi-nation tuna fishery developing in the tropical Atlantic nobody is attempting to keep records of total catch and effort as far as the author is aware. Except for the catches of Japanese fishermen the estimates of how much tuna are caught in the southwest Pacific and the Indian Ocean are little more than guesses, and it is not possible to tell from the published Japanese catch records the total amount of a particular species taken from a particular ocean area.

The Mandapam Camp Symposium recommended that: "Scientists in the countries of the world primarily concerned with the high seas fishery for tunas and bill fishes devise and publish a suitable system for gathering biologically useful statistics of yield and effort in these fisheries that will be capable of being employed on a world-wide basis, can be used uniformly by Fishery Officers and scientists everywhere, and that will be capable of yielding data useful in elucidating population dynamics of the several fish populations involved."

4 CONSERVATION PROBLEMS

In reviewing these three points it is necessary to reiterate that these are not solely matters of scientific interest but will be of serious diplomatic concern as well. Without wishing to go into detail it can be stated that there has been a good deal of irritation among the nations arising out of the tuna fisheries during the decade of the fifties. It may be confidently expected that this will recur and intensify during this decade if remedies are not found for the current lack of research on tunas, the fishery for them, and the relationship of fishing intensity to variation in fish abundance.

As a consequence of these problems (and similar ones in other fisheries) a whole series of conferences were held by the United Nations, the Organization of American States and their specialized agencies during the last decade. These culminated in the "Convention on Fishing and Conservation of the Living Resources of the High Seas" adopted by the First United Nations Conference on the Law of the Sea, held in Geneva, Switzerland in the spring of 1958. (Brittin and Watson, 1960).

Paragraph 2 of Article 1 of that convention clearly lays down the moral principle that will govern the family of nations in such matters and reads:

> "All States have the duty to adopt, or to cooperate with other States in adopting such measures for their respective nationals as may be necessary for the conservation of the living resources of the high seas.".

Other articles of this Convention prescribe the conditions under which fishermen can be regulated, either multilaterally or unilaterally, in their fishing operations on the high seas. Article 9 provides for compulsory arbitration in disputes arising out of these other provisions. Article 10 then becomes particularly pertinent. Paragraph 1 of it reads as follows:

> "1. The special commission shall, in disputes arising under article 7, apply the criteria listed in paragraph 2 of that article. In disputes under articles 4, 5, 6, and 8 the commission shall apply the following criteria, according to the issues involved in the dispute:
>
> (a) Common to the determination of disputes arising under articles 4, 5, and 6 are the requirements:
>
> (i) that scientific findings demonstrate the necessity of conservation measures;
>
> (ii) that the specific measures are based on scientific findings and are practicable, and,
>
> (iii) that the measures do not discriminate, in form or fact, against fishermen of other states.
>
> (b) Applicable to the determination of disputes arising under article 8 is the requirement that scientific findings demonstrate the necessity for conservation measures, or that the conservation programme is adequate, as the case may be."

Being aware that fishing states, despite the moral obligation in Article 1, might be unwilling or unable to control their fishermen for conservation purposes on the high seas far from home, this Convention provides in Article 7 that a coastal state under certain conditions can regulate the activities of fishermen of all nations off its coast without the consent of the other nations involved. Article 7 reads:

> "1. Having regard to the provisions of paragraph 1 of article 6, any coastal State may, with a view to the maintenance of the productivity of the living resources of the sea, adopt unilateral measures of conservation appropriate to any stock of fish or other marine resources in any area of the high seas adjacent to its territorial sea, provided that negotiations to that effect with the other States concerned have not led to an agreement within six months;
>
> 2. The measures which the coastal State adopts under the previous paragraph shall be valid as to other States only if the following requirements are fulfilled:
>
> (a) that there is a need for urgent application of conservation measures in the light of the existing knowledge of the fishery;
>
> (b) that the measures adopted are based on appropriate scientific findings;
>
> (c) that such measures do not discriminate in form or fact against foreign fishermen.

In essence this Convention lays down the moral obligation upon fishing states to prevent their nationals from overfishing any high seas resource and then, having a view to the moral frailties of humans and their institutions, gives the Coastal State a whip in the closet to bring out and use if the fishing States find it inconvenient to fulfil this moral obligation.

One thing requires to be pointed out additionally. In Article 10, paragraph 2 (a) (ii) the criterion, when the dispute is among fishing states is "That the specific measures are based on scientific findings and are practicable," but when the dispute is between a coastal State and a fishing State or States this criterion (Article 7, paragraph 2 (a)) reads "That the measures adopted are based on appropriate scientific findings."

The records of the conference will reveal that this difference in language is in recognition that the Coastal States frequently will not have elaborate and sophisticated research staffs, and that they thus can act under much less rigorous establishment of scientific fact than would be tolerated among fishing States.

What this plainly means is that the burden of proof in such instances falls upon the fishing State.

To review what should be involved in world-wide tuna research planning in respect of conservation these things may be suggested:

1. The catch of tuna from the world ocean is likely to double in the next ten years, creating numerous conservation problems, or suspicion thereof, which will result in diplomatic tension if the suspicion cannot be allayed by adequate scientific findings.

2. The fishing nations have the moral responsibility, and the practical necessity, of being able to prevent their fishermen from overfishing tuna on the high seas if they do not want their fishermen regulated on the high seas by coastal States on the basis of possibly flimsy scientific findings.

3. Basic to establishing whether conservation measures are required or not are three sorts of data, at least: (a) definition of species involved, (b) definition of homogeneous populations of a particular species, and (c) adequate and

current statistics of catch and effort upon that population of that particular species.

4. In no area except the Eastern Tropical Pacific are the tuna fishing countries adequately attending to these inquiries, and the record there is short of perfect.

5. There is no international or inter-governmental organization outside the Eastern Tropical Pacific which has the obligation, responsibilities, abilities or funds to provide the sort of data required to resolve the international conflicts which are certain to arise from the expanding high seas tuna fisheries of the world.

6. Time is required, under the most perfect conditions, for such studies to be brought to a useful state. The Convention for the Establishment of an Inter-American Tropical Tuna Commission was concluded in 1949, its operations were pressed with considerable speed, it had good cooperation, was able to obtain excellent staff from the start, and it turned out that its problems were somewhat simpler than they could have otherwise been. But it was 1955 before the Commission's staff was able to make statements about the condition of the tuna stocks in its charge with assurance, and another couple of years before it could be reasonably certain of its conclusions.

7. Accordingly the time which the tuna fishing countries have to attend to the diplomatic problems almost certainly approaching is limited.

5 HARVESTING PROBLEMS

There is another whole half of tuna research planning, however, which is more exciting, less grim, and likely to be positive and rewarding in its results. That is the application of ocean research to the increased production of tuna from the sea. Essentially this is concerned with, and aimed at, lowering the cost per ton of producing tuna with the objective of bringing to full fruition the productive potentials of the tuna populations of the world ocean at prices which consumers can and will afford. The methods, objectives, and progress of such research are well set out by Howard (Methodological Paper no. 4) and Uda (Methodological Paper no. 8).

Essentially what is wanted is to relate the circulation of the lower atmosphere with the circulation of the upper ocean, relate the circulation of the upper ocean with the aggregation of tuna in space and time, and relate the behavior of tuna to oceanic conditions, all to the end that the fisherman can locate, catch and land a load of tuna in the quickest time possible, with the highest reliability of being able to do it again, and with the lowest possible cost per ton of production. What is aimed at is reliable prediction of tuna aggregation in time and space from parameters of ocean or air conditions readily and customarily measured.

Sette (1961) and Howard (loc-cit.) after him have appropriately expressed the concern that the effort required to establish this knowledge and understanding may cost sums of money quite out of line with the value of the resulting fisheries. It may be noted that tuna are a sufficiently valuable fish that these worries are not quite so pertinent as with cheaper fishes. The million tons of tuna per year that the world's fishermen will be landing in a few years will bring them upwards of $200,000,000 per year, a valuation that will justify a good deal of even expensive high seas oceanographic research.

The fortunate part of this, however, is that man's curiosity and his needs in other fields of endeavor are driving him to extensive investigations of ocean and air processes which are yielding, and will yield, a considerable part of the more costly portion of the information required by the tuna ocean researcher. It is a fortunate thing that (a) the fashions of warfare have changed to undersea weapons, (b) it takes reasonably the same sort of information to catch submarines as it does to catch tunas, and (c) the Admirals have the same desire as the tuna people, to lower the cost per ton of their principle catch product, and the money with which to finance the required research.

Another force of ponderable size has rather recently risen in the family of nations which is already having consequential impact on these problems of tuna research associated with improving production because of its impact on general ocean research. This is associated with the growing realization that the nutritional future of mankind is associated with certain essential amino-acids, not calories, that these amino-acids are found in proportions suitable for human needs in fish, that there is much fish still available in the sea to fill these human needs, and that ocean research can lead to lowering costs of production to the extent that these fish can be made cheaply available to those that need and want them.

Lastly there is growing the political and humanistic desire in the industrial countries to aid the economic development of the non-industrial countries. Most of the latter are in the tropics and sub-tropics and many of them are adjacent to areas of sea where there are, or should be, large undeveloped tuna resources. Accordingly, development aid funds from several national, intergovernmental and international agencies are available for the required research.

An example of this sort of thing is the elaborate multi-nation ocean research project which is to begin in the Tropical Atlantic next year sponsored by CCTA/CSA[1] with material financial assistance from U.S.'s AID)[1] the United States government (under plans approved by the Interdepartmental Committee on Oceanography and under the field leadership of the Bureau of Commercial Fisheries), and the international community through the agency of UNESCO's Intergovernmental Oceanographic Commission. It is inevitable that this extensive survey program will yield information which will much enhance the production of tuna, especially in the eastern Atlantic.

Other examples of this sort are the large predevelopment fishery surveys financed by the Special Fund of the United Nations and executed by FAO's Fisheries Division in Peru and Ecuador, and presently under contemplation for Chile. The first two of these involve an expenditure of about $3,000,000 U.S. over a period of four years.

Another example of a multi-nation, multi-agency, multi-discipline approach to this problem is the projected "Cooperative Program of Study of the Eastern Tropical Pacific Ocean," (EPOC, 1961) sponsored jointly by the Eastern Pacific Oceanic Conference and the Inter-American Tropical Tuna Commission, and contemplating the expenditure of about $23,000,000 over an eight year period.

In these large programs tuna researchers have been involved in the planning from the start and, accordingly, results useful to the solution of tuna problems will fall out naturally. In the case of another even larger international oceanographic program, the mammoth thirty nation International Indian Ocean Expedition, this was not the case and there has been material concern evidenced that the fishery-useful information resulting from it will not be as great as it could easily be although it will be large. The Mandapam Camp Symposium recommended, that:

> "The authorities involved with the planning of the Indian Ocean Expedition give due consideration to gathering and collating the following sorts of information which would be useful in aiding the development of the high seas fisheries for Scombroid Fishes in the Indian Ocean.
>
> (a) Surface temperature charts on a monthly basis particularly from 20° south latitude to the Continent and Island chains on the north;
>
> (b) Variation in thermocline depth with monsoon change, particularly within two hundred miles of land in the Andaman Sea, Bay of Bengal, Arabian Sea, Persian Gulf and Gulf of Aden;
>
> (c) Variation in direction and flow of the mixed layer currents in the Indian Ocean, particularly north of 20° south latitude, and in particular as related to variation in monsoon period and strength;
>
> (d) Variation in basic biological productivity rate in the area north of 20° south latitude and particularly within two hundred miles of shore; and
>
> (e) Relationship of variations in these parameters to variations in the seasons and yield of the high seas fisheries of the areas."

The researcher associated with problems of enhancing tuna production falls rather naturally into a few categories which may, and probably will be, organized and acted upon in different ways. Among these are: (1) specialized studies concerning the relation of tuna to their environment, their reaction to environment changes, behavior, etc.; (2) specialized studies of oceanic processes to elucidate these problems; (3) general synoptic oceanic surveys over broad sea areas, and, (4) continuous monitoring of air and sea parameters suitable for use in prediction.

It is not unlikely that the first two sorts of research might be done mostly by national laboratories. At least that is, the way it is going now at BCF[1] Honolulu; BCF[1] San Diego; and STOR[1]. It is also likely that funds can be raised from national sources, and even sources related to tuna, adequate to the prosecution of most such studies. They are also of the sort that can be undertaken, perhaps best, by individual researchers or small teams, and whose results are often capable of extrapolated use to a good extent elsewhere in the world.

The general synoptic oceanic surveys, however, cannot practically be done by individual laboratories, or ordinarily entirely by national efforts, on the scale of geographic range suitable to tuna problems. Neither can they be financed exclusively on funds which are capable of being raised by tuna, or fishery, agencies. They can only practically be undertaken on the basis of multi-purpose use, and by international cooperation. Of such are the "Cooperative Program of Study of the Eastern Tropical Pacific Ocean" (EPOC, 1961), and the Guinean-Year-Tropical Atlantic Program.[2] It is to be noted also, that these grand surveys are not of a continuing nature but are for the purpose of elucidating oceanic problems of large geographic scale that cannot be solved by single or few ship expeditions. A good many problems arising in the world tuna scene do not seem possible of resolution without such large scale expeditions.

Such programs are the proper field of activity of the Intergovernmental Oceanographic Commission, and the prime reason for which it was established, because other users of the ocean are coming up against problems similar to ours. In such programs the requirements of all disciplines and of all interested nations require to be coordinated and modified this way and that to yield the greatest good to the largest interest, for the sums of money, the amount of ship-time required and the employment of trained personnel may be, and often is, of such magnitude as to draw heavily on potentials of these commodities available for use in national programs and be disturbing to them. In particular, for the successful prosecution of these oceanic surveys on a grand scale, it is necessary for the special desires and aspirations of the several sorts of ocean researchers to be submerged somewhat into the common good.

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[1] Please refer to page 11 for full names.

[2] Now called: Guinean Trawling Survey.

It has been for this purpose that a number of persons interested in tuna and other fishery research have been particularly interested in the organization of IOC, the relations of SCOR and FAO to it, and the general problem of promoting good will, understanding and cooperation among fishery oceanographers and other oceanographers. It was to accentuate this need that the Mandapam Camp Symposium adopted the above quoted resolution in respect of the International Indian Ocean Expedition.

With the far ranging tunas, to an even greater degree than with many other fishes, it is necessary to find out how the broad open ocean works and how its movements relate to atmospheric movements and geostrophic forces. Tuna and fishery oceanographers can materially assist such broad and expensive programs but cannot ordinarily mount them alone. Accordingly, cooperation with others is mandatory, whether desired or not. Controversy between fishery oceanographers and physical oceanographers cannot really be afforded by either because each requires the support of the other in order that these grand scale ocean surveys can be mounted and carried to successful conclusion in good time.

Of the fourth sort of ocean research noted above, continued monitoring, we do not have sufficient experience yet to say much. Some thinking on this is set out in the above noted EPOC report. It seems obvious that these continuing monitoring projects, as they come into being, will require to be of an international nature as to support and execution, and also that they will require to be of multidiscipline use - physical oceanography, chemical oceanography, biological oceanography, fishery oceanography, meteorology, etc.

6 CONCLUSION AND RECOMMENDATIONS

Having now had a series of international conferences on tuna, oceanography, and related subjects in the last few years one wonders what can be done about it all. An international conference takes up a great deal of time of researchers, many of whom would have much rather stayed home and continued their studies. The preparation of papers is not an easy task; journeying to far places takes time and money; regardless of what the home office or wife may think the average international conference is a pretty wearing experience on the participants. One would like to see something useful come of it all.

The Dakar, Honolulu and Mandapam Camp Symposia each produced a series of solid recommendations are set out in Information Paper no. 3[1] of this conference. These recommendations were worked on hard and seriously by the participants. Some of them are beginning to produce results but it must be frankly admitted that most of them are like the desert dust upon the wind, gone and soon forgotten. People go off from the conference to their busy lives elsewhere and the high resolves of joint thinking are soon submerged in the new tasks of individual effort. The record of achievement of such resolutions is not high.

It seems certain that the present conference will also result in a number of resolutions. The recommendations from the several regional conferences perhaps will be recast into new, more generally applicable, and more refined form. New ones will be added that had not been thought of by the regional conferences. One cannot even glance through the mass of excellent papers prepared for this conference without seeing the resolutions bubbling forward to highlight needs for particular group actions to be taken or to be accentuated. The committees of the conference appointed to deal with these matters will labor seriously and long into the night to perfect the thought content and polish the presentation of the recommendations. The conference in final plenary session will again go over them to enhance their elegance before their final acceptance. The accepted ones will be mimeographed and added to the report of the conference to the warm satisfaction of all who were involved in their preparation.

THEN WHAT WILL HAPPEN TO THEM?

The author suggests that the conference does one other thing: appoint a continuing Committee on Implementation.

This need not be a large group and certainly should not be more than fifteen in number. It should be composed of competent persons who are sufficiently interested personally in these matters to give the Committee persistent drive that will last over the years required to see to the implementation of the resolutions and recommendations arising from the conference. Whilst such a committee may require to be heavily drawn from government personnel it should have on it a solid sprinkling of experts having sufficient seniority and status so that they can act with greater individuality than is permitted to most public servants, and there should be added, if possible, some academic or other persons capable of high freedom of individual judgement to enforce the drive of the Committee. There should be as good a geographic spread of committee members as is possible.

The function of the Committee on Implementation should be just what the name connotes: to see that the resolutions and recommendations resulting from this conference become translated into competent action.

The author thinks that such a Committee could carry out most of its function by correspondence and by the actions of its individual members, or small groups of them, in their local theatres of action and in other international and national forums where they are active from time to time. It would not be inappropriate that they should report back from time to time to the conference upon their progress, thus giving the conference some semblance of continued life. It certainly should be possible that they could call upon other conference members and persons for aid in their task.

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[1] Appendix I of Vol. 1 of the Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species.

This conference differs from some in that the more active participants are well known to each other and will be thrown even more together in the immediate future as the problems concerned with the tunas and their harvesting press more strongly on the international scene, as they seem bound to do. Accordingly, such a Committee on Implementation may not be so radical a scheme as it seems at first, for the tuna researchers of the world are a finite and rather close-knit group of people already, with similar problems that are more and more becoming world wide in scope. This coherence on a world wide basis seems bound to increase under the force of common need.

The author is not sure of the appropriateness of making such a recommendation to a conference called under the auspices of the Fisheries Division of FAO and it is not sure what the relations of such a Committee on Implementation should be to FAO in a continuing way, or whether FAO could countenance any such relationship - or Committee. It is not sure either, what the reaction will be to such a recommendation of national delegates to a conference of this nature.

What is sure, is that the tuna fisheries of the world are going to increase steadily in scope and intensity. They are going to generate conservation and competitive tensions that have proven their ability heretofore of seriously disturbing the international scene. Aside from this they have the capability of greatly wasting a resource needed by mankind either by not preventing overfishing or by countenancing underfishing. While science cannot resolve all the problems that will arise in such a connection the example of the Inter-American Tropical Tuna Commission is before us as to how competent science can relieve many such stresses through increasing knowledge and understanding.

The author is also sure that this conference will bring forward many recommendations which, if put in train, would lead to a more rational use of the tuna resources of the world, which, as living resources of the high seas are the common concern and property of all mankind. The author would like to see those recommendations translated into action. Accordingly, it is recommended that the conference create a continuing Committee on Implementation to see that this is done.

1/ AID - Agency for International Development
CCTA/CSA - Commission for Technical Co-operation in Africa South of the Sahara - Scientific Council for Africa South of the Sahara
STOR - Scripps Tuna Oceanography Research
BCF - Bureau of Commercial Fisheries

Experience Paper No. 1

PRELIMINARY EXPERIMENTS WITH TILAPIA AS BAIT IN THE TUNA FISHERY OFF THE COAST OF BRAZIL[1]

by

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Abstract

This paper describes the results obtained using tilapia (Tilapia melanopleura) as bait in long-lines for the capture of tunas and related species.

Three experiments were carried out using two types of bait for comparison: the 'samma' (Cololabis saira) and tilapia. The number of baskets and hooks used as well as the species of fishes caught and their respective quantities, are listed in a table. According to the results obtained the tilapia was as efficient as the 'samma' but further experiments are necessary to reach definite conclusions.

ESSAIS PRELIMINAIRES D'EMPLOI DES TILAPIAS COMME APPAT DANS LA PECHE DU THON AU LARGE DES COTES BRÉSILIENNES

Résumé

Le document décrit les résultats obtenus dans l'emploi de tilapias (Tilapia melanopleura) comme appât dans la pêche aux palangres des thons et espèces voisines.

On a procédé à trois essais, deux types d'appât étant utilisés aux fins de comparaison: le 'Samma' (Cololabis saira) et le tilapia. Un tableau énumère les données relatives au nombre de paniers et d'hameçons utilisés ainsi qu'à l'espèce et au nombre des poissons capturés. Selon les résultats obtenus, les tilapias constitueraient d'aussi bons appâts que les 'Samma', mais d'autres expériences seront nécessaires avant que l'on puisse établir des conclusions définitives.

1/ A popular version of this study was published under the title "Utilização de tilápia como isca de espinhel para tunídeos e afins", in Boletim de Estudos de Pesca, 1(1):13-17, SUDENE, Recife, Brazil, October 1961.

EXPERIMENTOS PRELIMINARES CON TILAPIA COMO CEBO EN LA PESQUERIA DE ATUN DE LAS COSTAS DEL BRASIL

Extracto

En este trabajo se describen los resultados obtenidos utilizando tilapia (Tilapia melanopleura) como cebo en los palangres para la captura de atunes y especies afines.

Se llevaron a cabo tres experimentos utilizando dos clases de cebo con el fin de efectuar comparaciones: el 'samma' (Cololabis saira) y la tilapia. El número de cestos y anzuelos utilizados, así como las especies de peces capturados y sus cantidades respectivas, figuran relacionadas en el cuadro. Según los resultados obtenidos, la tilapia fue tan eficaz como la 'samma', aunque es preciso realizar nuevos experimentos para llegar a conclusiones definitivas.

The development of a longline fishery for tunas and related species by Japanese vessels on a special contract with the Brazilian Government, is relatively new. A summary of the history of this fishery is given by de Paiva (1961) and de Moraes (in press).

Since the beginning, the bait has been Cololabis saira imported from Japan, where it is known as 'samma'. There have been some experiments with other baits, namely Hemirhamphus brasiliensis and Sardinella aurita (or allecia), but none of these on the offshore longliners or on a truly commercial scale. Although there are possibilities which SUDENE intends to pursue in the future, of developing other suitable baits, tilapia was considered first because of its exceptional qualities of resistance and reproduction in almost any body of water without particular difficulties for the fish culturist. Also, species of tilapia have been used for many years as live bait in the Pacific tuna fisheries.

The tilapia now cultured in Brazil is Tilapia melanopleura, introduced from Africa by the Fish and Game Department of the Federal Ministry of Agriculture. This species is used by the Pisciculture Division of the National Department for Prevention of Drought (DNOCS), for the stocking of reservoirs in the northeastern section of the country. The Pernambuco State Department of Animal Production has also shown interest in T. melanopleura. The 2, 500 fishes used in the experiments described here were furnished by Mr. Benedito César, a local fish-culturist.

The work was carried out on board the Junei Maru 8, the Japanese vessel owned and operated by the INBRAPE Fishing Company of Recife, with the endorsement of Admiral Augusto Dias Fernandes, Commandant of the Third Naval District. All experiments took place during normal commercial fishing operations, and the working days and areas selected in such a way that the loss would be minimum should results prove negative. Because of this consideration, the ship's officers themselves chose the areas and times for the experiments.

All the work was done between 15 and 19 October 1961, between 1° and 2° N lat., and 28° and 30° W long., (some 600 nautical miles northeast of the northeastern extremity of the South American land mass), where the depth is about 2000 m. The surface water temperature was about 26°C, and the weather generally cloudy with strong winds and occasional fine rain. Setting of the longline began about 4 a.m. and took about 4 1/2 hours. Hauling began at noon or later and usually finished at midnight or shortly thereafter, with the direction of hauling always the reverse of the direction of setting. In the experimental sets the hooks were baited alternately with tilapia and samma, so that as nearly as possible the experimental conditions were controlled for equal exposure of the two baits.

The figures in Table I clearly show that tilapia used as bait for this fishery in general gives results equal to samma (Chi-square tests of the total numbers captured demonstrate no significant difference). There is some evidence of differences for the individual species captured but the numbers involved are too small for detailed analysis - further experiments are required.

The high yield per unit effort obtained by the Japanese longliners fishing off the coast of Brazil in recent years(de Moraes in press), using samma exclusively as bait, indicates that a change in bait is not a matter to be taken lightly. In discussing the work in advance with persons interested in the fishery, several theoretical disadvantages of tilapia were pointed out : the dark coloration, the smaller size but greater weight in relation to samma, etc. However, the experiments apparently demonstrate that these differences may not be as important as believed.

In addition, the samma received from Japan has been subjected to processes known to improve its characteristics as bait : selection for size and form, washing, treatment with oils to prevent dessication, and other special handling. In fact, the production of samma bait is an industry in itself, especially in the city of Choshi, where there are at least four firms which export bait all over the world. The tilapia used were less carefully selected and treated - individuals varying from 6 to 18 cm were chosen (there is indication that tilapia for tuna bait should be from 10 to 13 cm only). The frozen tilapia used were of dull and dark coloration, probably due to their

Table I
Results of experiments with samma and tilapia as tuna bait

Species captured[1]	Experiment I (15-16 Oct.)		Experiment II (17 Oct.)		Experiment III (18-19 Oct.)	
	Gear No. baskets: 360 No. hooks: 1,800		Gear No. baskets: 234 No. hooks: 1,670		Gear No. baskets: 260 No. hooks 1,300	
	Bait		Bait		Bait	
	Samma	Tilapia	Samma	Tilapia	Samma	Tilapia
Bluefin	5	2	7	5	3	4
Bigeye	4	7	4	7	10	9
Yellowfin	5	4	3	3	4	8
Albacore	15	14	18	14	12	9
Swordfish, sailfish, marlins	13	8	8	7	6	4
Others	2	8	5	6	4	5
Totals	44	43	45	42	39	39

[1] English common names correspond to Portuguese common names and to scientific names as given by de Paiva (1961) and de Moraes (in press).

origin in turbid waters, but after having been on the hooks in the water for some hours the color brightened considerably. A definite advantage of tilapia is the resistance to maceration. While samma after several hours on the hook tends to fall apart, as shown by the condition of the bait at time of hauling, tilapia is so resistant that at times difficulty was experienced in removing it from the hook after exposure as bait for several hours.

It is planned to continue these experiments for more definitive results.

Experience Paper No. 2

INVESTIGATION OF TUNA BEHAVIOR BY FISH FINDER

by

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Abstract

To fish for tunas scientifically, one must know tuna behavior, swimming depth, speed and school density. Many methods have been used to gather these data, but have not offered sufficient conclusive evidence. In this paper, the author proposes use of a fish finder. After many experiments, it has been established that a fish finder can effectively detect tuna schools and make tuna investigations. First, the author discusses the properties of a fish finder able to detect tunas at a depth of 200 m, and concludes that the instrument must have a sounding depth of more than 3, 000 m to operate efficiently. Secondly, data are mentioned on swimming depth, speed and school density, procured by fish finders in the seas around Japan and in the South Pacific Ocean. These data establish that the swimming depth depends on the degree of illumination of the sky. The relationship between the shape of the banks in the grounds and the distribution of tunas is also explained. Finally, the maximum speed of albacore, yellowfin and bluefin tuna was observed and appeared to be about 2 or 3 knots under normal conditions; school density was about 0.0001 to 0.0003 fish per cubic meter.

ETUDE DU COMPORTEMENT DU THON AU MOYEN D'UN APPAREIL A REPERER LES POISSONS

Résumé

La pêche scientifique du thon requiert des connaissances sur le comportement du poisson, la profondeur à laquelle il se déplace, sa vitesse de nage et la densité des bancs. Parmi les nombreuses méthodes employées pour rassembler ces données, aucune n'a donné de résultats suffisamment concluants. L'auteur de la présente note propose d'utiliser à ces fins un appareil à repérer les poissons. De nombreux essais ont permis d'établir qu'un tel appareil peut effectivement détecter les bancs de thons et permettre l'étude du comportement de ce poisson. L'auteur examine tout d'abord les caractéristiques d'un appareil capable de détecter les thons à une profondeur de 200 mètres, et conclut que, pour donner satisfaction, le dispositif doit pouvoir sonder à plus de 3 000 mètres. Il cite ensuite des données sur la profondeur de nage, la vitesse de nage et la densité des bancs, obtenues à l'aide d'appareils à détecter les poissons au large du Japon et dans le Pacifique Sud. Ces renseignements établissent que la profondeur de nage dépend du degré d'intensité lumineuse du ciel. Le document fait également état du rapport entre la configuration des bancs se trouvant sur les fonds de pêche et la répartition des

thons. Enfin, il rend compte d'observations sur la vitesse maximale du germon, du thon à nageoires jaunes et du thon rouge, qui paraît être de l'ordre de 2 ou 3 noeuds dans des conditions normales. La densité des bancs était de l'ordre de 0,0001 à 0,0003 poisson par mètre cube.

INVESTIGACION DEL COMPORTAMIENTO DEL ATUN CON EL LOCALIZADOR DE PECES

Extracto

Para la pesca con carácter científico del atún es necesario conocer el comportamiento de este animal, la profundidad y la velocidad a que nada y la densidad de los cardúmenes. Para recoger tales datos, se ha recurrido a muchos métodos, pero éstos no han ofrecido una prueba bastante concluyente. En este trabajo, el autor propone el empleo de un instrumento localizador de peces para realizar tales observaciones. Despues de muchos experimentos, se ha comprobado que un localizador puede detectar eficazmente los cardúmenes de atún y efectuar investigaciones sobre éste. En primer lugar, el autor examina las propiedades de un aparato localizador que sirva para la detección de atunes a una profundidad de 200 m., y llega a la conclusión de que este instrumento, para funcionar eficazmente, debe tener una profundidad de sondeo de más de 3.000 m. En segundo lugar, se indican los datos sobre profundidad y velocidad a que nadan y sobre la densidad de los cardúmenes, obtenidos mediante fonolocalizadores en los mares que rodean al Japón y en el sur del Océano Pacífico. Estos datos muestran que la profundidad a que nadan depende del grado de iluminación del cielo. Igualmente se explica la relación entre la configuración de los bancos en las zonas de pesca y la distribución de los atunes. Por último, se observó la velocidad máxima a que nada la albacora y los atunes de aleta amarilla y aleta azul, viéndose que era de unos 2 ó 3 nudos en condiciones normales; la densidad de los cardúmenes era aproximadamente de 0,0001 a 0, 0003 de ejemplar por metro cúbico.

1 INTRODUCTION

To fish for tunas scientifically, it is necessary to have a knowledge of the behavior of the fish. In particular, depth of the swimming layer and the daily changes in it, speed of swimming, and school density, are directly related to the catch. Many methods have been used to observe these data, but have offered no conclusive evidence. To increase the efficiency of observation, the author has experimented with a fish finder.

Fish finders have, until now, been used by tuna boats only to find banks located in the fishing grounds, and not for fish detection. Recently, through the development of electronic techniques, a special fish finder has been devised for this purpose. Numerous field experiments have shown that fish finders may also be useful in the investigation of tuna behavior.

This paper deals with the properties of a fish finder which can be used for tuna investigation, and gives some examples of tuna behavior observed in the fishing grounds around the Japanese coast and in the South Pacific Ocean.

2 FISH FINDER FOR TUNA INVESTIGATION

2.1 Salient features required in the fish finder

Improved manufacturing techniques in Japan today offer all kinds of fish finders suitable for the various types of fishery, namely trawl, midwater trawl, tuna and deep-sea fishing.

Tuna schools are generally less dense than other schools. Consequently, to locate the school, the acoustic power, pulse transmission, beam angle and sounding range must be properly selected. Also the observation of D.S.L. (Deep Scattering Layer) is important in order to know the migration of the tuna. The fish finder must therefore have the capacity for D.S.L. detection.

The ultrasonic reflection loss of the fish body and of D.S.L. are known through experiments; the values are about 15 decibel at 28 kc, 8 db at 200 kc for yellowfin, and 20 db at 28 kc, 12 db at 200 kc for albacore. The reflection loss of D.S.L. is about 40 to 60 db within the range of 20 to 200 kc. Fig. 1 shows the relationship of ultrasonic reflection loss of tuna versus frequency through 10 to 400 kc (Hashimoto 1959, Nishimura 1961a).

It is necessary to transmit sufficient ultrasonic power to detect the tuna school. The ultrasound transmitted from the transducer at the surface propagates with attenuation by spherical diffusion and absorption, and reaches the bottom. The ultrasound reflects at the sea bed with subsequent reflection loss and returns to the receiving transducer at the surface. These relationships are shown in the following equation.

$$20 \log_{10} P'_{2x} = 20 \log_{10} P_{01} - 20 \log_{10} 2x - L_b - 2\alpha x \qquad (1)$$

For tuna detection, however, the tuna becomes a sound source, therefore the reflected wave returns again affected by spherical diffusion, and the equation is as follows:

$$20 \log_{10} P'_{2x} = 20 \log_{10} P_{01} - 40 \log_{10} x - L_p - 2\alpha x \qquad (2)$$

where α : absorption coefficient in db/km
P_{01}: output acoustic pressure at unit distance (1m) from transmitting transducer
P_{2x}: receiving sound pressure at the point of 2 x of distance from transmitting transducer (for sea bed
P'_{2x}: receiving sound pressure at the point of 2 x of distance from transmitting transducer (for tuna)
L_b: reflection loss on sea bed
L_p : reflection loss on tuna

Comparing equations (1) and (2), the terms of attenuation were $20 \log_{10} 2x$ in equation (1), and $40 \log_{10} x$ in (2); the attenuation is greater for tuna detection than it is for sea bed detection.

Fig. 2 shows the relation between the depth and P_{2x} or P'_{2x}. The abscissa indicates the depth in logarithmic scale and coordinates the relative sound pressure in db. The curve (A) indicates P_{2x} and curve (B), P'_{2x}. The difference of sound level in Fig. 2 between P_{01} and point B indicates reflection loss of tuna, and difference between P_{01} and point D, $20 \log_{10} 2 + L_b$.

Supposing the depth of tuna to be 200 m, and the reflection loss 20 db at 28 kc, then P_{01} may be indicated by the sound pressure of point C, namely 114 db. This value is the minimum sound pressure to detect tuna at 200 m.

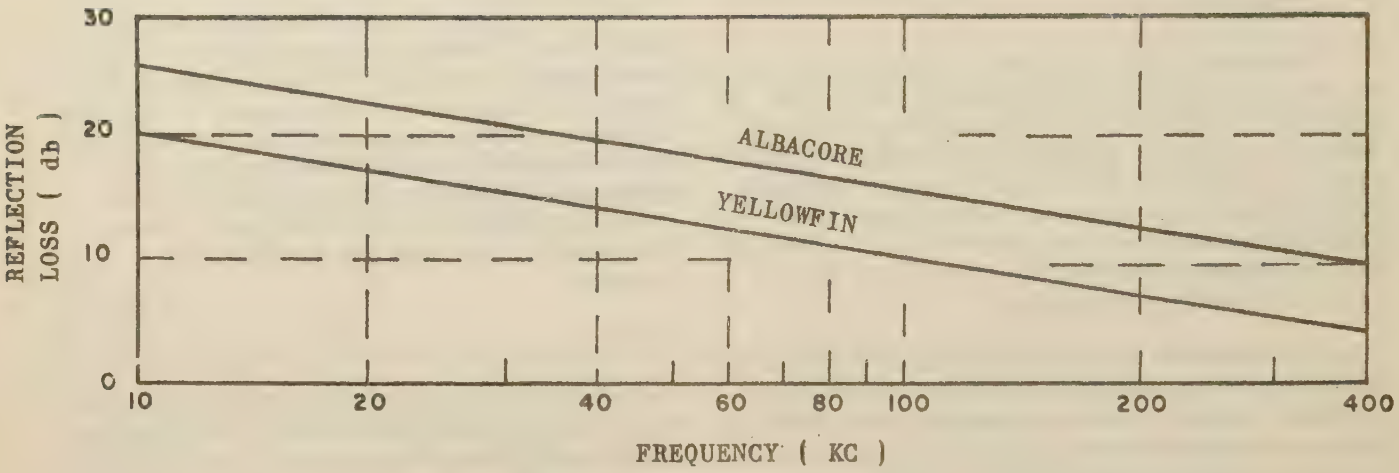

Fig. 1 Relation between frequency and reflection loss of tuna

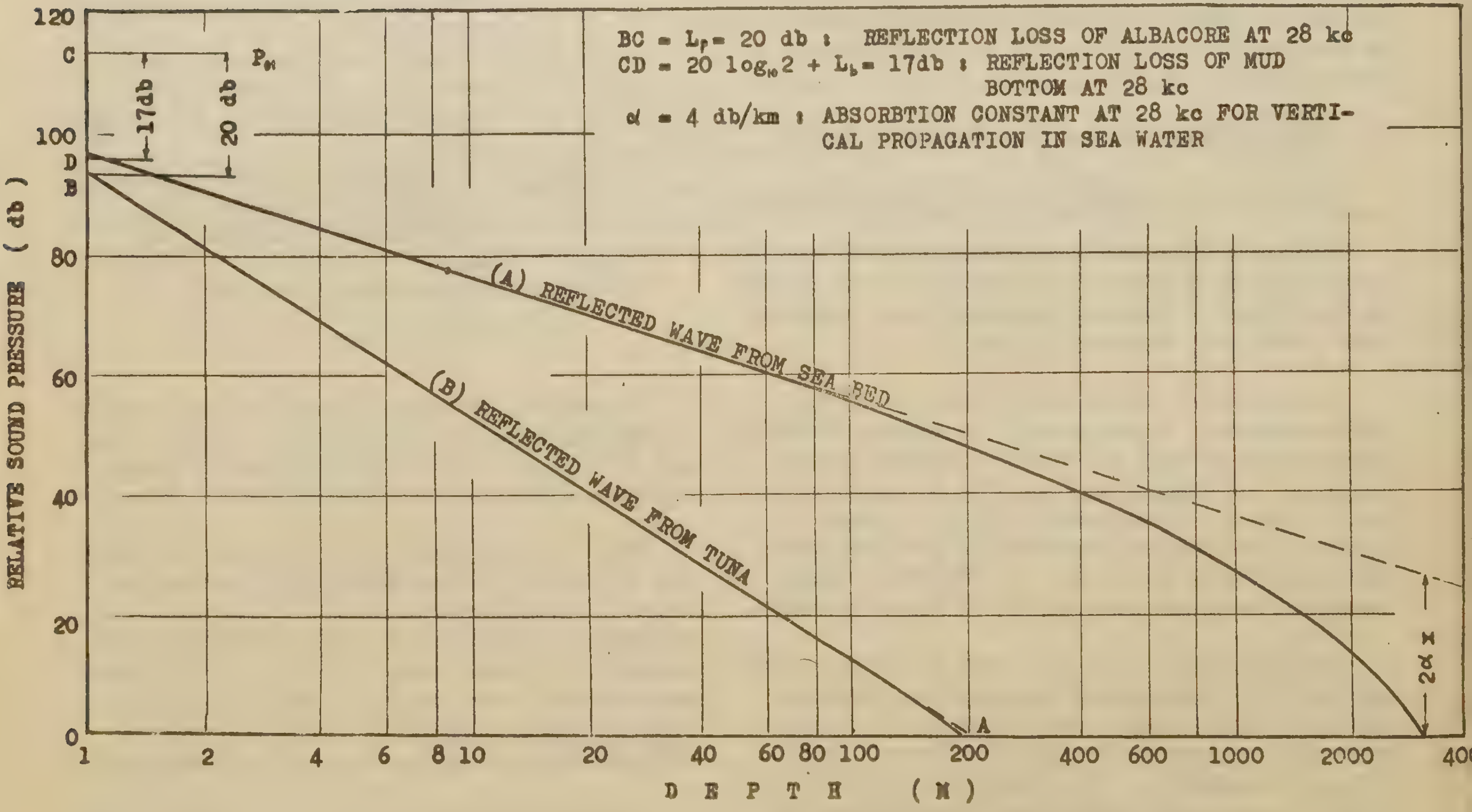

Fig. 2 Relation between depth and relative sound pressure

Calculating this value in terms of the capacity for echo sounding the sea bed, as the reflection loss is 11 db for muddy sea bed at 28 kc, the cross point of curve (A) and abscissa which indicates 0 db, 3000 m, shows the maximum capacity for echo sounding the sea bed. In other words, it is necessary to use an echo sounder with ability of more than 3000 m to detect a tuna at a depth of 200 m.

In actual application, the ultrasound would be attenuated by the bottom hull of the ship or by the bubble layer generated under the bottom hull. These points must be taken into consideration and the fish finder for tuna must transmit intense acoustic power more than that indicated in Fig. 2. (Nishimura 1961a).

2.2 Description of the fish finder used

The ultrasonic pulse transmission, sounding range of recorder, width of sonic beam, etc. of the fish finder must be designed bearing in mind the density and swimming speed of the tuna school. For instance, a fish finder must be able to transmit frequent ultrasonic pulses, enlarge sounding range, and make a wide beam angle. The following fish finder, which was used in the experiment, is an example of apparatus designed to suit these requirements.

Frequency	28 kc
Range	(0-100) x 5 m
for recorder	(0-120) x 5 m
	(0-600) x 5 m
for C.R.T.	33.3/40 m
Transmitting system	valve oscillation
Output power	3 kW
Pulse transmission	90/75/15 per minute
Paper speed	21/17.5/3.5 mm/min
Transducer	AF alloy
size	163 x 270 mm
beam angle	$11.5^{\circ} \times 8.2^{\circ}$
Maximum sounding capacity	6000 m
Maximum tuna finding capacity	500 m

3 IDENTIFICATION OF TUNA

Identification of fish appearing on the record of the fish finder is important but difficult. An acoustic technique, measuring the sound pressure of reflected wave from tuna, offers some solution. The kind and size of tuna can be roughly identified by measuring the sound pressure of reflected wave on the amplifier of the fish finder (actually the intensity of echo on recording paper is measured by attenuator), when the output pressure and also the reflection loss of tuna is known, as mentioned above.

Fig. 3 shows a record obtained on the fishing grounds of the north eastern seas of New Zealand; each small triangle-like mark indicates a fish. Fig. 4 shows measured values of intensity of fish which appeared on this echo-chart. The abscissa indicates depth in meters, coordinate sound pressure in db. Mark(.) shows measured value for fish swimming in a deep zone of 20 to 100 m and which are recorded intensively on the paper, and mark (x) indicates fish in the shallow zone. As the transmitted acoustic pressure of the fish finder used in this measurement was known, drawing the curves of attenuation for different reflection loss from 15 to 60 db (Fig. 2), these measured values show that they are closly within the range from 15 to 60 db. In other words, some of the echoes marked (.) with a value of 15 to 20 db seem to be albacore or yellowfin. The mark (x) seems to indicate small fish about the size of sardine or mackerel, as the value was not intense.

Fish caught in this fishing ground are given in Table I; it seems that the fish with low reflection were yellowfin and albacore, while others with high reflection loss were Myctophum flying fish, ray, etc. (Nishimura 1961a).

4 SWIMMING DEPTH OF TUNA

Swimming depth of tuna seemed to vary with different conditions, namely water temperature, salinity, water current or tide, kind of tuna, distribution of bait fish, day or time, location and shape of sea bed, etc. The author would like to mention here some examples of swimming depth of tuna.

4.1 Daily periodical change in swimming depth of tuna

A continuous observation of the depth at which the tuna swims was interesting and instructive. Fig. 5 shows the change of swimming depth of tuna as obtained in the fishing grounds off north eastern New Zealand. During the night, the recording paper of the fish finder was filled with hazy echo-like D.S.L. and the trace of fish could almost not be seen

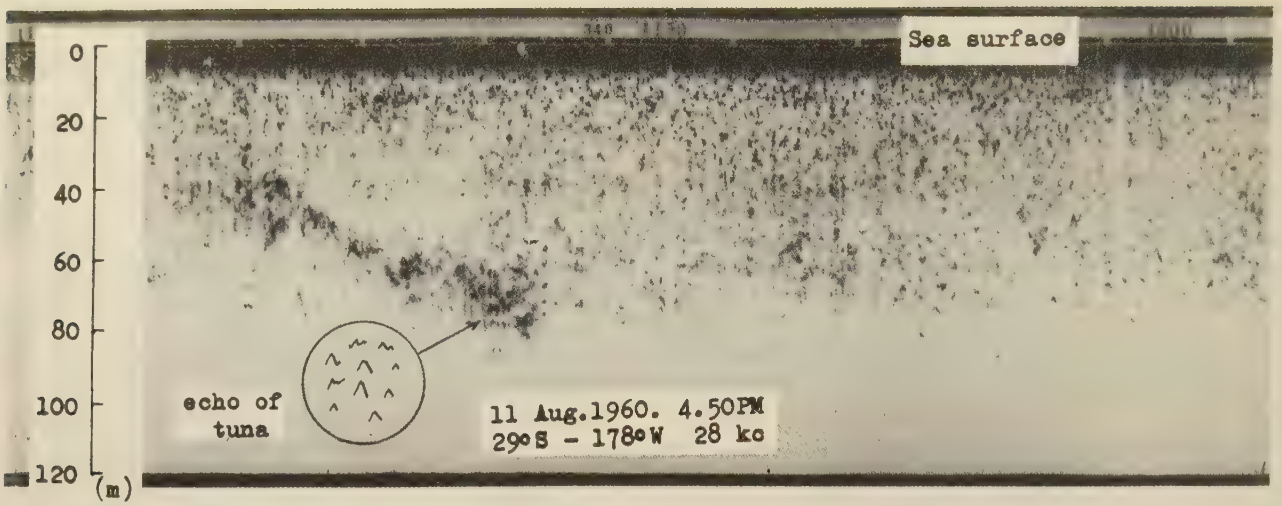

Fig. 3 Echo trace of tuna as recorded in New Zealand waters. Each triangle indicates a tuna.

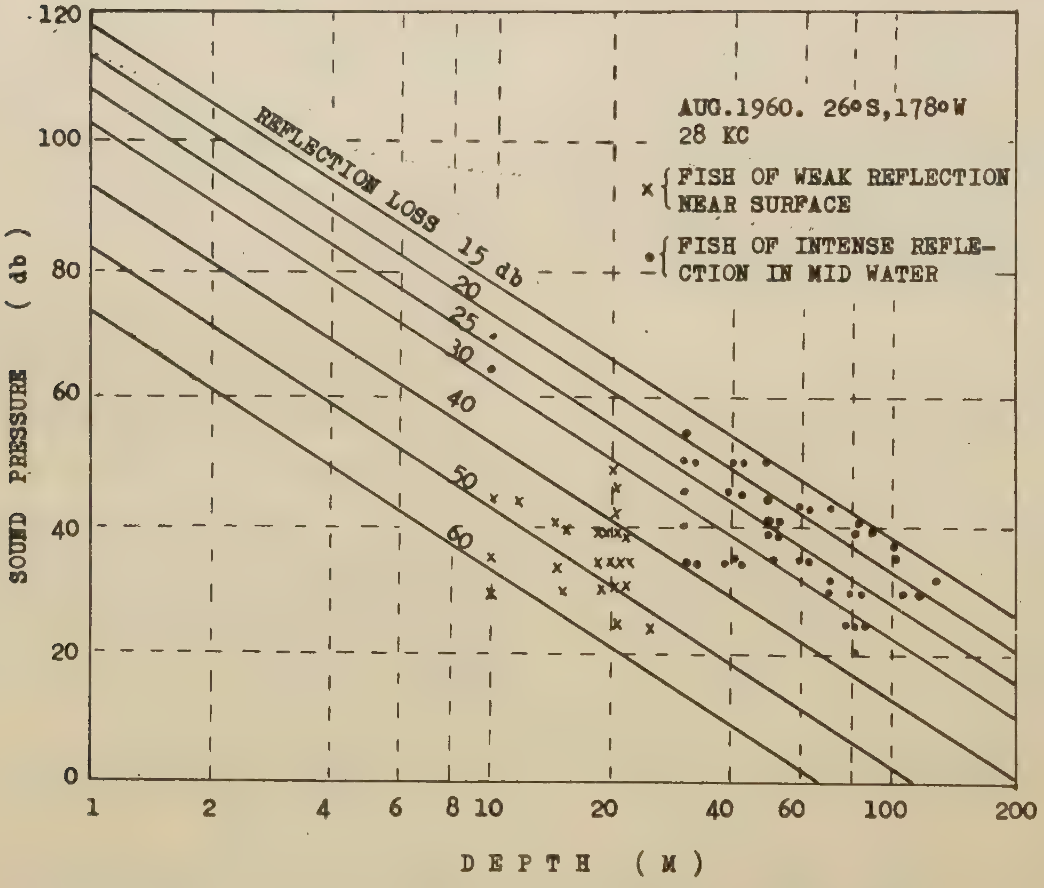

Fig. 4 Identification of tuna by acoustic measurement. Each curve indicates intensity of reflected wave from various reflection loss, and (.) or (x) show measured value for fish echoes.

TABLE I

Fish caught in the fishing grounds off north eastern New Zealand

Name of fish	Weight (kg)	Length (cm)	Percentage of catch
Albacore	10 - 20	90 - 102	60 - 80
Yellowfin tuna	14 - 23	106 - 120	10 - 20
Bigeye tuna	22 - 70	108 - 158	3 - 10
Skipjack	10 - 15	80 - 90	5 - 15
Barred marlin	80 - 100	200 - 250	
Sword fish	50 - 100	200 - 300	
Shark	80 - 200	200 - 400	
Ray		30 - 50	5 - 10
Others			
Total:			100

TABLE II

Fish found in the stomach contents of yellowfin and bigeye tuna

Name	Size (cm)
Chiroteuthis sp.	5 - 10
Polypus sp.	
Chauliodus sloani	20 - 25
Exocoetus volitans	10 - 15
Xenolepidichtys dalgleishi	5
Centrophorus petersi	7 - 10
Taractes sp.	7 - 10
Myctophum sp.	3
Nemichtys sp.	10
Garinaria lamarki	1 - 2

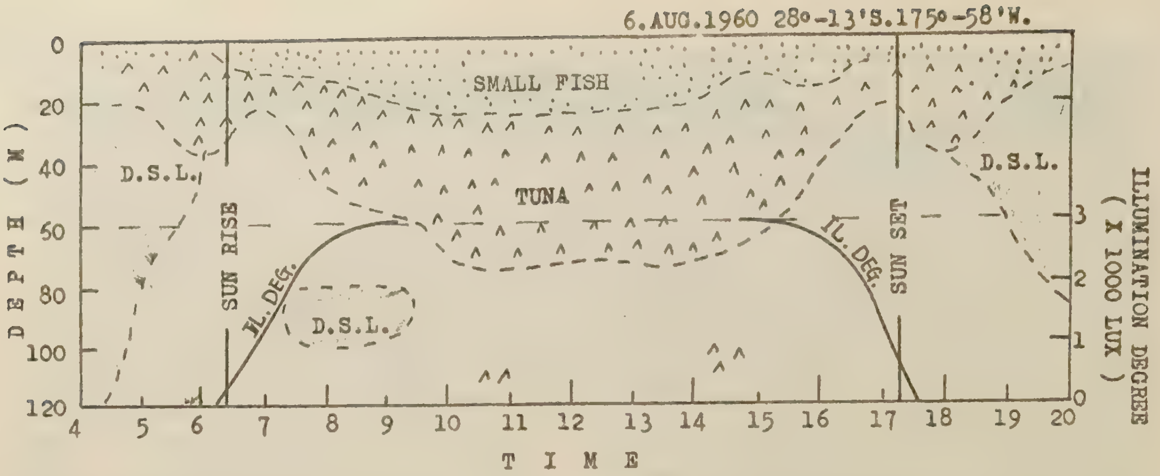

Fig. 5 Daily change in swimming depth of tuna as recorded in New Zealand waters. Change of illumination degree versus time is shown.

in the deep zone. But in the morning, about sunrise, the fish layer went slowly down into deep waters. In one or two hours after sunrise, this layer reached the depth of 40 to 80 m. No remarkable change could be seen in the depth of layer of fish during the day-time. Toward the evening, the fish layer began to rise slowly at the speed of about 20 or 30 m per hour, and fish were only recorded near the surface after sunset. During the 17 days of experiment, the pattern of movement of the tuna from day to day was found unchanged. Similar findings have been recorded by other experiments conducted in other areas, and it has been concluded that the movements of the tuna are as mentioned above.

The rising and sinking of tuna in the morning and in the evening respectively seems to be related to the degree of illumination of the sky. The measured value for this illumination was noted in Fig. 5. When the sky starts brightening in the morning, the layer of fish sinks with the increasing light, rising again in the evening as the day darkens.

4.2 Tuna around bait fish

The echo-chart in Fig. 6 shows the relationship between the depth of the tuna and the existence of the bait fish school. The small triangle in the deep 60 to 120 m zone indicates yellowfin tuna (many yellowfin were caught in this area). The continuous black traces show dense schools of small bait fish. (Table II).

4.3 Tuna around bank

In the fishing grounds of the bluefin tuna, in Tsugaru Strait, in the northern offshore of Shimokita Peninsula, Aomori Prefecture, Japan, tuna gather around the bank of Oma. Fig. 7 shows an echo-chart obtained by using a 28 kc fish finder, and each triangular mark indicates blue fin tuna. The depth of the sea bed changes steeply from 200 m to 60 m as shown in Fig. 8. Tuna were distributed in a wide area, the distribution being especially dense at the steep incline. The depth of the tuna was measured at about 100 m in the deep zone and at a few meters in the shallow zone.

5 SWIMMING SPEED AND SCHOOL DENSITY

5.1 Swimming speed

The swimming speed of fish may be calculated from the echo trace appearing on the recording chart of the fish finder. When the ship speed is known, the swimming speed can be calculated from the height and width of the fish echo. When tuna traverses the cone of sound, the distance between fish and transducer changes depending on the position of the tuna in the cone, and the distance is smallest when the tuna is located in the center of the cone. This difference is indicated on the recording chart as depth difference or height of echo trace. The time to traverse the cone is indicated on the chart, the width of echo trace.

By such a method, we can calculate maximum speed of the tuna. The result showed that the maximum speed was within the range of 2 to 3 knots for yellowfin, albacore and bluefin tuna respectively. Previously, it has been thought that the maximum speed of the tuna exceeded 10 knots, but it has been noted that the speed is very slow under normal conditions.

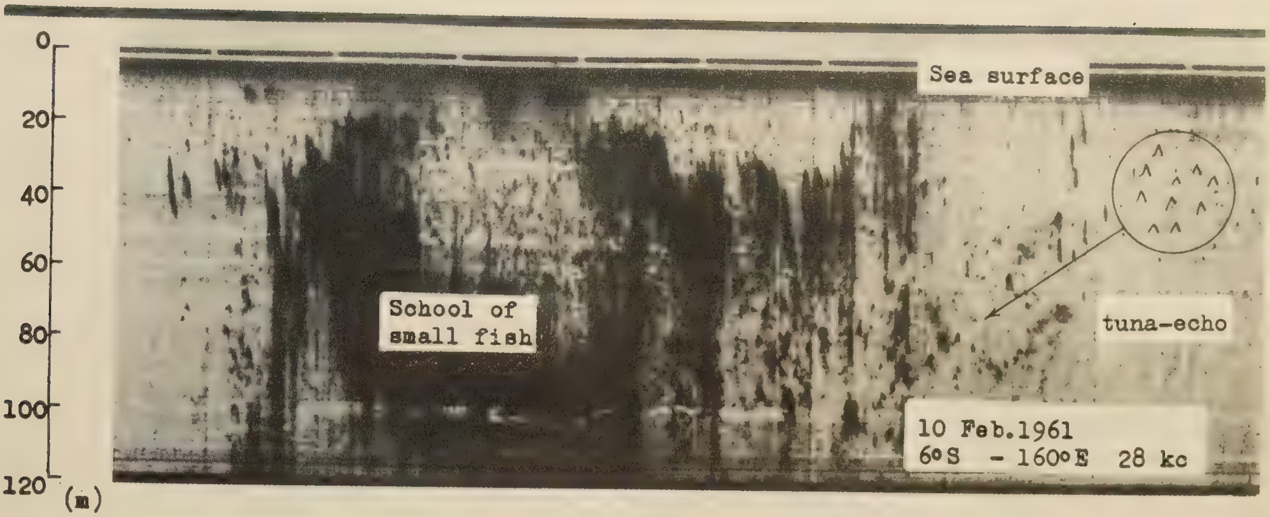

Fig. 6 Distribution of yellowfin around school of small fish. This record was obtained in the sea east of the Solomon Islands

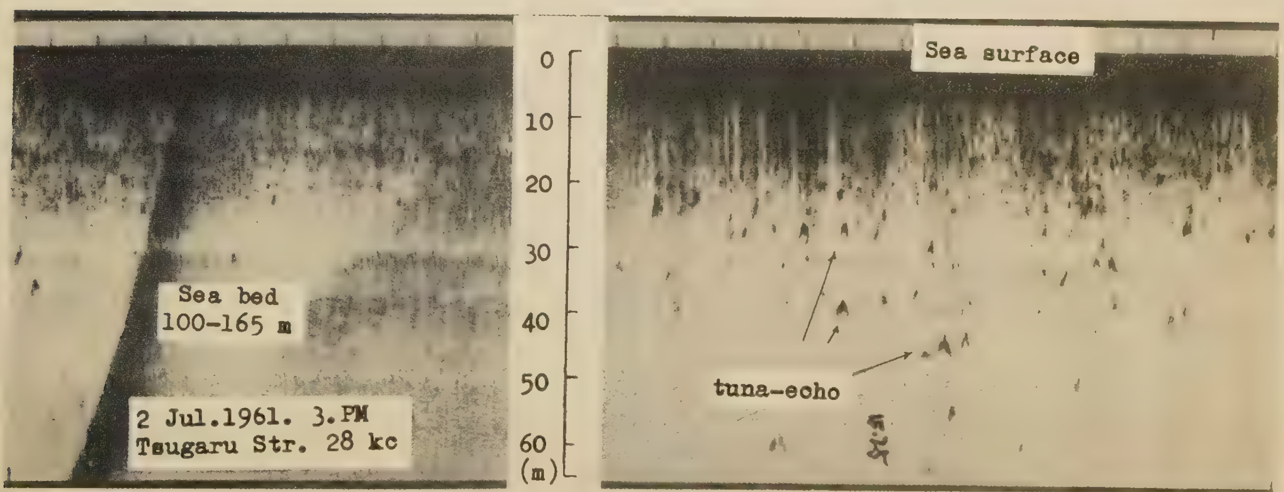

Fig. 7 Echo chart of bluefin tuna in Tsugaru Straits. Each triangle is a tuna-echo

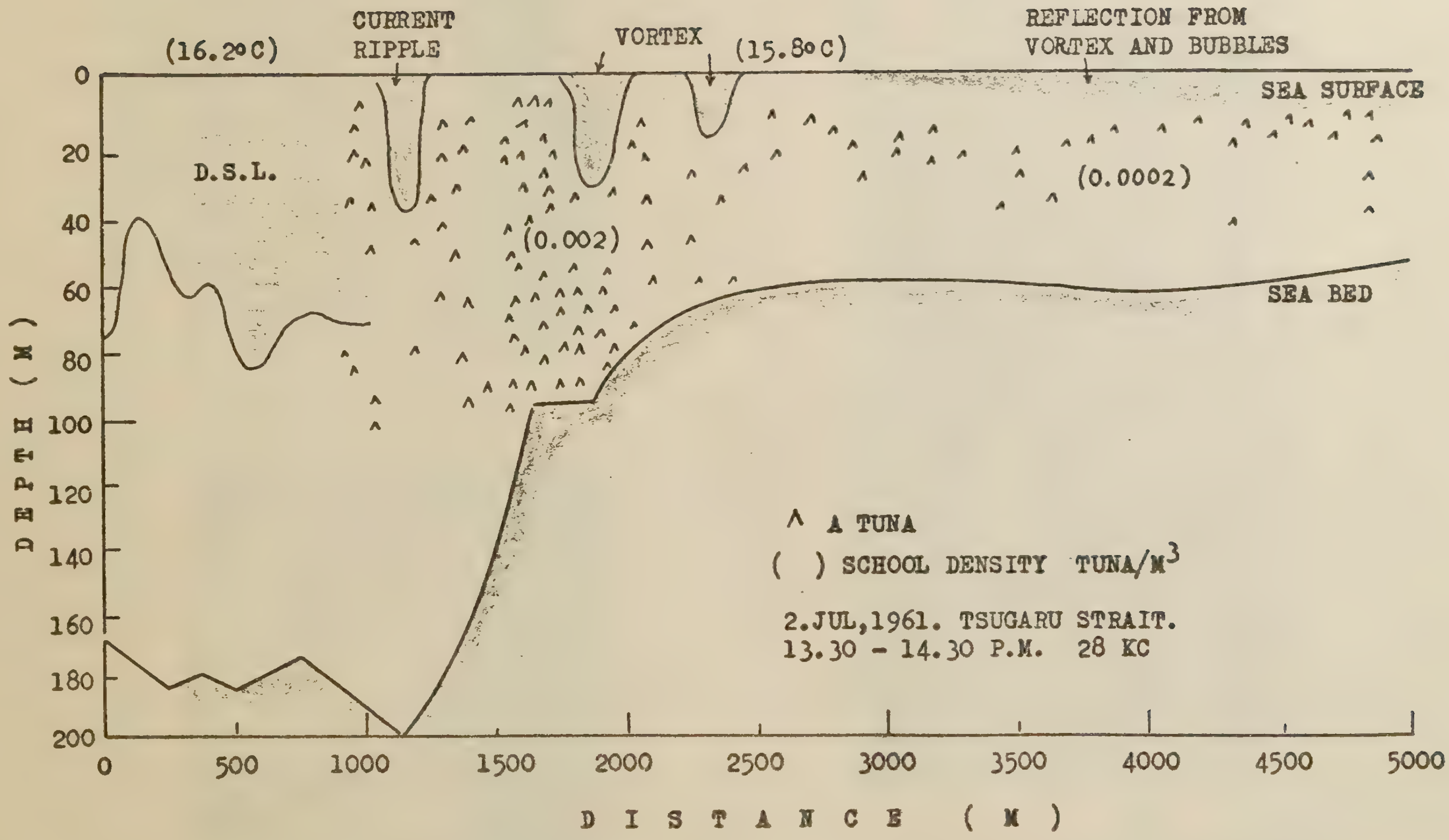

Fig. 8 Distribution of bluefin tuna around bank - obtained by continuous echo-chart

5.2 School density

The density of the fish school can also be calculated from the echo-chart. The density can be calculated only when each fish appears on the recording chart, as shown in several examples. An accurate calculation cannot be expected because the beam width of the ultrasonic transmission which depends on the reflection of fish is not clarified. In this case, however, the calculation was based on the supposition that the beam of sound was a circular cone, and the beam angle a half power beam angle for the combined directivity of transmitting and receiving transducer. The density of tuna may be calculated by the ratio of the mass created by the cone within the given time space and the quantity of tuna in this mass.

The calculated values show that the density of tuna schools was as follows: for albacore in the southern Pacific Ocean, 0.0002 to 0.0003 tuna/m^3, for yellowfin; 0.0001 tuna/m^3; and for bluefin tuna along the Japanese coast 0.0002 tuna/m^3 (maximum 0.002 tuna/m^3).

Comparatively the values given above do not differ greatly and these data should be of considerable help in future observations.

6 CONCLUSION

The author believes that his new investigation method will contribute to better observation of tuna behavior, and is also of the opinion that observations will be made much easier and more accurate through use of a fish finder. This paper does not describe the full results on tuna behavior obtained by means of a fish finder as this method of observation is still in its infancy, and future statistical observations are expected.

Experience Paper No.3

TUNA TAGGING EXPERIMENTS IN NORWEGIAN WATERS

by

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Abstract

During the years 1957-61, 224 bluefin tuna were tagged and released on the Norwegian coast. So far 22 recoveries have been reported. In one case, the wound caused by the tag was examined and found to be completely healed. The within-season recaptures corroborate a migration pattern found by size frequency analyses of the commercial catches. The change in the migration pattern from the southern to the northern route at about 12 years of age is substantiated by a tag recovery. The between-season recaptures demonstrate a certain exchange of tuna between Spanish and Norwegian waters. Due to subdivision of the stock, it is assumed that long series of data are necessary to elucidate the identity of this tuna population.

ESSAIS DE MARQUAGE DE THONS DANS LES EAUX NORVEGIENNES

Résumé

De 1957 à 1961, 224 thons rouges ont été marqués, puis libérés, au large de la côte norvégienne. On a récupéré jusqu'ici 22 de ces poissons. Dans un des cas, il a été constaté, après examen, que la blessure causée par le marquage s'était parfaitement cicatrisée. Les recaptures effectuées durant la campagne confirment le schéma de migration qu'avait permis d'établir l'analyse des statistiques des pêches commerciales du point de vue de la répartition par taille. La reprisé d'un poisson marqué confirme que vers l'âge de 12 ans les thons, au lieu de continuer à émigrer en direction du Sud, se dirigent vers le Nord. Les recaptures effectuées dans l'intervalle entre campagnes indiquent que certains échanges ont lieu entre les eaux espagnoles et les eaux norvégiennes. En raison de ces diversités, on estime que l'identité de cette population de thons ne pourra être établie qu'au moyen de longues séries de données.

EXPERIMENTOS DE MARCADO DE ATUN EN AGUAS NORUEGAS

Extracto

Durante los años 1957-1961, se marcaron y soltaron en aguas noruegas 224 ejemplares de atún de aleta azul. Hasta el momento, se han recibido noticias de haber sido recapturados 22 ejemplares. En uno de los casos, se examinó la herida causada por la marca, comprobándose que había cicatrizado completamente. Las recapturas dentro de la misma temporada confirman el régimen de migración comprobado mediante estudio de la frecuencia de tallas en las capturas comerciales. La variación de la ruta sur a la norte en el régimen de migración a los 12 años de edad aproximadamente, viene confirmada por la recuperación de una marca. Las recapturas entre temporadas diferentes demuestran un cierto intercambio del atún entre las aguas españolas y las noruegas. Debido a la subdivisión de la población, se supone que serán necesarias largas series de datos para aclarar la identidad de esta población atunera.

1 INTRODUCTION

Of the tuna species, only the bluefin (Thunnus thynnus L.) commonly occurs in Norwegian waters. These tuna, on feeding migration after spawning, usually arrive at the Norwegian coast in the first half of July. Only adults penetrate so far north, the tuna being five years or more before they appear in the catches. The biggest tuna arrive earliest in the season (July) and travel farthest north. The smaller and younger fish arrive later (August-September), and are only caught off the southwest coast. In October the tuna usually disappear from these waters (Hamre 1958).

The tuna are caught with a specially constructed purse-seine developed in the late 1940's. In 1959, 1960 and 1961 the fishery yielded 2.8, 2.5 and 6.7 thousand metric tons respectively.

2 TAGGING PROGRAM

The Institute of Norwegian Fishery and Marine Investigations has carried out investigations on tuna since 1955, aimed at widening knowledge of the natural resources upon which the tuna fisheries depend. Tagging experiments constitute an important part of the research program, and attempts have been made to develop a suitable method for tagging this large and powerful fish.

The first step was to construct a tag which could be fixed easily and quickly to the fish. For this purpose, a new method of applying the Lea tag was developed, based upon the principle of harpooning. A small harpoon, to which a Lea tag is attached by nylon, is inserted into the muscle of the fish by means of a thin stainless steel pipe (or cylinder) mounted on a bamboo stick, 1.5 m. long (Fig. 1). In the first experiments in 1957 the harpoon was made of stainless steel (model A, Fig. 1), but this was later changed to plastic materials (models B and C). The plastic harpoons have four flexible barbs, and are machined from rod stock.

Models A and B were inserted by means of a hollow pipe, model C by a small, solid steel cylinder fitting into a hole in the base of the harpoon. Model C was found to be the most successful in the tagging operations and has been used since 1959.

The tagging procedure is adjusted to purse seine caught fish. Twenty-two fish were tagged and released in 1957 using tag model A, 18 tuna in 1958 using model B, and 42, 62, and 80 tuna were tagged in 1959, 1960 and 1961 respectively using tag model C. The taggings were carried out in the area marked V and VI in Figure 3. No individual measurements of the tagged fish were made.

The tuna were grouped as "good", "less good", and "doubtful", according to their apparent condition when released. In the period 1958 to 1961, 14 of the 202 tuna tagged were regarded as "less good", and 11 were noted as "doubtful". The remaining 177 seemed to be in "good" condition when released.

3 RESULTS

So far, 22 recovered Norwegian tuna tags have been reported. Details of the recaptured fish are given in Table 1. None of the 22 tuna tagged in 1957 with the stainless steel harpoon, has been recovered. All the recaught fish, except one, belong to the tuna released in "good" condition, recovery No. 17 having been classed as "doubtful". Recoveries Nos. 1, 3, 4, and 10 were caught by tuna traps, No. 9 by angling, and the rest by Norwegian purse seiners.

In one case (No. 10), the part of the muscle in which the harpoon was inserted was examined. The wound from the harpoon was found to be completely healed. The harpoon and nylon were surrounded by a thick layer of connective tissue, forming an open channel through which the nylon filaments were running. The outer part of the channel was bent backwards, obviously due to the water resistance of the tag, the opening being 2.5 cm behind the insertion point (Fig. 2).

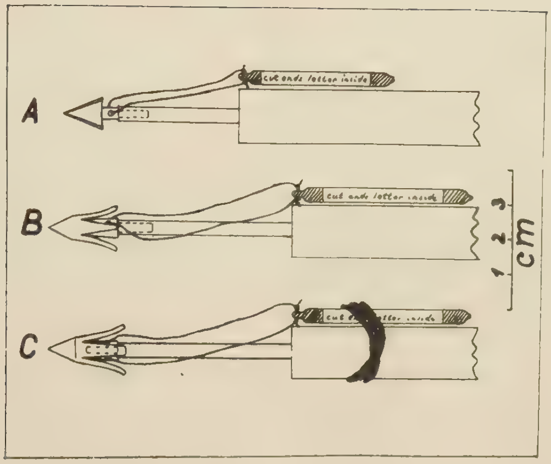
The within-season recaptures indicate a migration southward along the coast (districts V - VII, Fig. 3), except for recovery No. 21 (Table I) which was recaught to the north of the release locality at the very end of 1961 season.

During the years 1959-1960, four long-term recoveries were made in Spain and three in Norwegian waters; an additional six recaptures were made in Norwegian waters in 1961, while none was reported from Spain. It may be noted that all but one of the long-term Norwegian recoveries were recaught in the area where the tagging was executed. The exception (No. 17) was recaught in northern Norway in 1961.

Table I

Release and recovery data for Norwegian tagged bluefin tuna

Recovery No.	Release Date	Release Locality	Recapture Date	Recapture Locality	Days in Liberty	Weight in kg.(w)
1	15 Sept. 1958	N 59°35', E 5°04'	20 June 1959	Cadiz, Spain	278	138
2	15 Sept. 1958	N 59°32', E 5°04'	20 Aug. 1959	N 59°55', E 5°00'	339	138
3	17 Sept. 1958	N 59°38', E 5°02'	19 June 1959	Cadiz, Spain	275	176
4	17 Sept. 1958	N 59°38', E 5°02'	4 July 1959	Cadiz, Spain	290	153
5	10 Aug. 1959	N 60°55', E 4°25'	17 Aug. 1959	N 60°15', E 4°45'	7	218
6	10 Aug. 1959	N 60°55', E 4°25'	17 Aug. 1959	N 60°00', E 4°45'	7	223
7	12 Aug. 1959	N 60°30', E 4°40'	17 Aug. 1959	N 60°30', E 4°40'	5	-
8	12 Aug. 1959	N 60°30', E 4°40'	18 Aug. 1959	N 60°05', E 4°50'	6	218
9	21 Aug. 1959	N 59°30', E 5°05'	6 Oct. 1959	Anholt Is.	46	170
10	21 Aug. 1959	N 59°40', E 4°55'	20 May 1960	Cadiz, Spain	273	217
11	1 Sept. 1959	N 59°55', E 4°55'	1 Aug. 1960	N 61°52', E 4°35'	335	102
12	8 Sept. 1959	N 59°44', E 4°51'	19 Sept. 1960	N 61°02', E 4°20'	377	113
13	8 Aug. 1960	N 60°47', E 4°15'	17 Aug. 1960	N 60°39', E 4°20'	9	231
14	8 Sept. 1959	N 59°44', E 5°00'	5 Aug. 1961	N 60°43', E 4°35'	697	163
15	8 Aug. 1960	N 60°44', E 4°29'	31 July 1961	N 60°51', E 4°35'	358	163
16	8 Aug. 1960	N 60°44', E 4°29'	28 Aug. 1961	N 60°18', E 4°49'	385	180
17	9 Aug. 1960	N 60°30', E 4°42'	3 Aug. 1961	N 66°15', E 10°30'	359	224
18	25 Aug. 1960	N 60°24', E 4°50'	18 Aug. 1961	N 61°03', E 4°25'	358	136
19	16 Aug. 1961	N 60°44', E 4°40'	30 Aug. 1961	N 59°41', E 5°00'	14	198
20	21 Aug. 1961	N 60°44', E 4°38'	28 Aug. 1961	N 60°08', E 4°58'	7	180
21	28 Aug. 1961	N 60°15', E 4°50'	6 Oct. 1961	N 60°50', E 4°40'	39	146
22	3 Sept. 1959	N 60°15', E 4°45'	30 Sept. 1961	N 60°40', E 4°40'	758	-


A
B
C
cut ends letter inside
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1 2 3
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Fig. 1. Models of tags used in tagging the bluefin tuna on the Norwegian coast

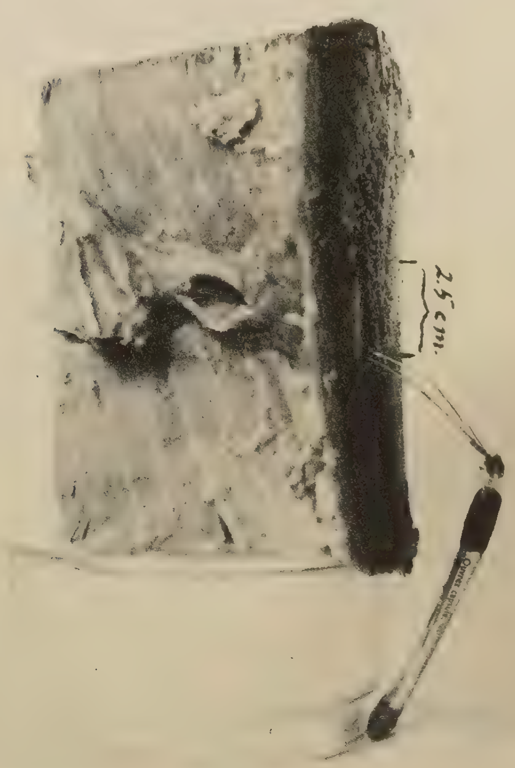

Fig. 2. Harpoon with attached nylon lodged in dorsal muscle of bluefin tuna (after 273 days of liberty)

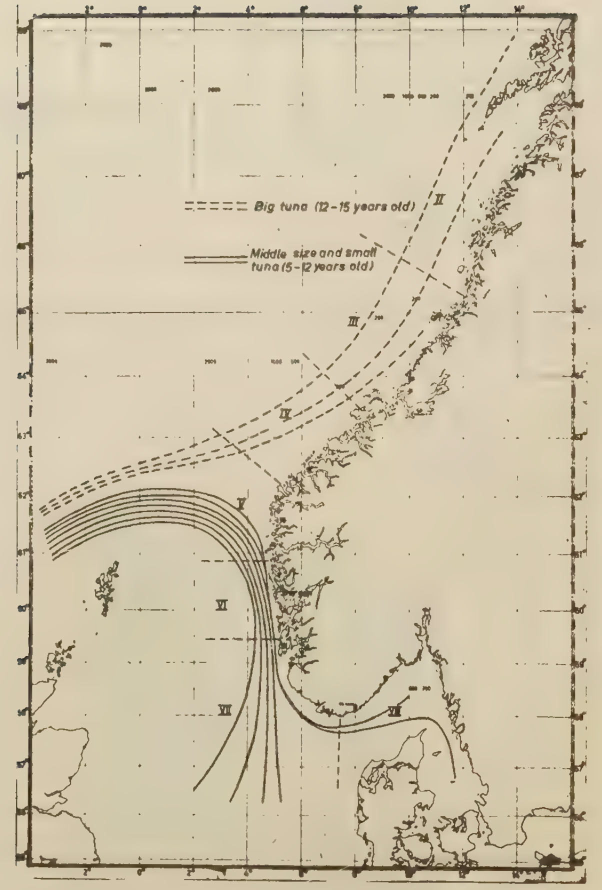
Big tuna (12-15 years old)
Middle size and small tuna (5-12 years old)
II
III
IV
V
VI
VII
VIII

Fig. 3 Immigration routes of bluefin tuna to the Norwegian fishing grounds. The numerals II-VIII refer to fishing districts.

4 DISCUSSION

The migration of tuna indicated by the within-season recoveries, corroborates the migration pattern found by weight frequency analyses of the commercial catches (Hamre 1961). The season may be divided into an immigration and an emigration period, the main part of the catch usually being taken during the former. Fig. 3 shows the immigration routes the tuna seem to follow along the Norwegian coast. It can be seen that the biggest tuna (12 years or more), migrate to the north, and the smaller ones (5 to 12 years old), towards the south. In accordance with this, the fishing grounds are divided into a northern fishing area including districts I - III, and a southern one including districts V - VIII. District IV is regarded as a transition area, in which small quantities of tuna have been caught. The number of fish caught in the two areas in 1959 to 1961 is as follows:

	Northern area	Southern area
1959	1,668	13,724
1960	1,674	19,924
1961	9,451	29,222

These figures show that the northern area has gained in importance from 1960 to 1961. This is in accordance with the more northern migration of the bigger tuna, deduced from the size frequency analyses. In fact, it was forecast before the 1961 season started, that a strong year class (1949) was on the verge of changing its migration pattern. In this light, recovery No. 17 becomes very interesting, furnishing direct evidence for the conclusion drawn by the size studies.

The emigration routes of the tuna are less known. However, during the very end of the seasons, catch statistics indicate a northward migration along the coast of districts V and VI. This is obviously tuna on their way back to the Atlantic Ocean. These fish are often very difficult to catch, and consequently the yield during the emigration is usually low. In 1961, however, the catch at the late season in districts V and VI was good. Recoveries Nos. 21 and 22 show the presence of emigrating tuna, but the size composition pattern together with two American tagged fish recaught at that time indicated that a new run of tuna from the other side of the Atlantic Ocean had invaded the area concerned. (Anon. 1961)

The yearly catch of adult tuna in Spain is usually higher than in Norway, and the long term recoveries of 1959-1960 may be taken to corroborate the common supposition that the same tuna population is being exploited. According to personal correspondence, the Spanish caught about 27,000 fish in 1961, and there should thus have been a fair chance for recaptures of Norwegian tagged fish provided that their fishery is based upon the same stock and that the tagged fish are randomly distributed. Evidently this is not the case due to a certain sub-division of the stock. Attention has been drawn to the different size of the tuna appearing in northern and southern Norway. Furthermore, it has been shown that the stock appearing in the southern area also is sub-divided by size, making up contingents of fish which visit the coast in succession (Hamre 1958). So far, we have little knowledge to what extent the stock is split up into several bodies and to what extent they rejoin throughout the year. Although the data so far available are inadequate for any definite conclusions, one may point to some interesting features concerning the distribution of tagged fish.

Size frequency data from the southern area indicate three runs of tuna migrating southward during the 1961 immigration period. The data are grouped in weekly catches. Table II gives the weeks by number, approximate yield of each run and number of long-term tags recovered.

Table II

Tuna immigration period 1961
Approximate yield of each run
and long-term tags recovered

Weeks No.	1st run 28 - 30	2nd run 30 - 32	3rd run 33 - 36
Fish caught	10,000	5,000	9,000
Recaptures	0	2	2

The size composition of the first run differs from those of the two other, because the 1952 yearclass is poorly represented. As the main part of the fish tagged in 1959 and 1960 was released from catches considerably mixed with the 1952 yearclass, the tag density of the first run must be expected to be low, especially as this run obviously contains the most fish. A distribution of the recoveries as shown in Table II, is thus quite reasonable. According to personal information, unfavorable fishing conditions on the Spanish coast took place during a certain period of the 1961 season. The lack of Norwegian tagged tuna may have been due to this fishing condition coinciding with runs 2 and 3.

The questions discussed above, demonstrate the complexity of the problems concerning identity and migration of the Atlantic bluefin tuna stock. It is reasonable to assume that long series of tagging data combined with size-frequency analysis of catches from the different fishing areas may elucidate these problems.

Experience Paper No. 4

MEASUREMENT OF THE SHAPE OF THE TUNA LONGLINE AND AN ANALYSIS OF ITS EFFICIENCY

By
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Abstract

The author describes a study, conducted in 1957, on the shape of the tuna longline and suggests possible improvements. He wishes to stress how increased catch will result from improved gear, used in conjunction with fish-finding devices. Further details may be found in "Technical Report of Fishing Boat", No. 11 (Fishing Boat Laboratory), Tokyo.

MESURE DE LA FORME DE LA PALANGRE A THON EN PECHE ET ETUDE DE SON EFFICACITE

Résumé

L'auteur expose les résultats d'une étude effectuée en 1957 sur la forme que prend dans l'eau la palangre à thon et suggère des améliorations possibles. Il insiste sur l'accroissement des prises que permet l'emploi d'un engin perfectionné conjointement avec des dispositifs de repérage du poisson. Pour des renseignements plus détaillés, se reporter à "Technical Report of Fishing Boat", No. 11 (Fishing Boat Laboratory), Tokyo.

MEDIDA DE LA FORMA DEL PALANGRE ATUNERO Y ANALISIS DE SU EFICACIA

Extracto

El autor describe un estudio, efectuado en 1957, de la forma del palangre atunero y sugiere posibilidades de mejora, poniendo de relieve que si se emplea un aparejo perfeccionado en unión de aparatos localizadores de la pesca se obtendrán capturas más abundantes. Para más detalles, consúltese Technical Report of Fishing Boat", núm. 11 (Fishing Boat Laboratory), Tokio.

1 INTRODUCTION

In 1949, when engaged in field trials on the purse seine, the author first became aware of instruments which could detect fish in the water or could trace fish from aboard fishing vessels. Little was then known of the fish finder. The author later undertook a series of experimental trips working with this equipment.

It is now comparatively simple to locate tuna with the fish finder, though there are certain difficulties. When individual tuna are near small sardines, they are usually recorded as a school. Ultrasonic waves are reflected separately, and most deep-swimming tuna tend to swim independently or in small schools. Ultrasonic waves, therefore, have a limited time in which to detect active tuna.

There had been few positive records of detected fish in Japan until a number of trials were made with an instrument that permitted the selection and adjustment of power of the ultrasonic waves, pulse-emitting interval, and resolving effect. These early experiments were successfully carried out by Nishimura of the Fishing Boat Laboratory, Tokyo.

Clippers may now locate the whereabouts of tuna with comparative ease, making it possible to exploit the fishing grounds fully with suitable fishing gears and methods.

In the following paper, the author describes a study concluded in 1957, on the shape of the tuna longline, so as to encourage an increase in fishing effort to make use of fish finding devices.

Experimental measurements of the geometrical shapes formed in longline gears were carried out in the Indian Ocean from February through May 1957. At the time of the experiment, the swimming depth of the tuna was not detected by most of the leading skippers who had paid out gears by rule of thumb. The only way they could find the fish, was to vary the depth of the baited hooks.

2 SHAPE AND HOOK-DEPTH OF LONGLINE

When neither tide nor wind are affecting the line, the catenary assumed by the main line can be described by measuring the hanging depth at any part of the line where branch lines are attached, since the shape of the catenary is determined by the length of the main line and the sitting speed. The main line does not ordinarily sink so deep, however, as the geometrical catenary.

Under the influence of varying water flow and wind, the main line bends horizontally or vertically as shown in Fig. 1 (front view), Fig. 2 (bird's-eye view), and Fig. 3 (side view). Table I summarizes measurements obtained in the trial. Factors affecting the shape of the line are: current speed, course of the line in relation to the direction of the current, wind strength and direction, and distance between buoys or setting speed.

The distance between the buoys, and the angle formed by the line in response to the current, are measurable. Water flow effects and those of wind may be anticipated and adjusted.

Measurements obtained in experimental studies are only useful for providing an approximate guide to the fishing depth. It would be advisable to have the length of main lines adjustable between buoys so that baited hooks may be concentrated at a chosen depth.

In addition, the line should be of light material, with smooth water flow characteristics, i.e. circular in cross section and smooth on the surface. The specific gravity of the material should be maintained within a practicable range, since the heavier material gives a catenary of better shape because of increased stiffness of the twine.

The result, of course, is not so perfect a fishing method as to be instantly applicable, but it pays to know how to set main lines to assume a proper catenary, thus reducing the action of the wind on the surface buoys and flags.

The bearing of the main line must be carefully checked in respect to current direction and also as regards the curvature of the branch lines at various positions along the main line.

Serious tension is generated between buoys if 300 to 450 baskets of longline gear are paid out successively. It is best to set them out in 50-basket units so as to eliminate tension factors.

For the salmon gill net fishery, the author once advocated the desirability of using discon-

Table I

Measurements of the longline obtained during the trial

Kuremona (Dyed by coal-tar)(Contains a leadline)	Cotton (Dyed by coal-tar)	Kuremona (Dyed by coal-tar)	Items
Fig. 1	Fig. 2	Fig. 3	
5	4	5	Number of hooks
19.6 m	18.2	18	Buoy line length
252 m	245	302	Main line length
21.4 m	21.4	22.8	Branch line length
1.75	1.4	1.23	Specific gravity of line
180 m	185	180	Distance of buoys
323°	338	270	Direction of line
293°	180	0	Direction of current
___ kt	1.5	0.5	Current speed
130°	350	0	Direction of wind
6 m/sec	5	4	Wind speed
___°	160°	0	Direction of wave
___ m	1.5-2.0	0.5-1.0	Wave height
___ sec	7	8-10	A period of wave
30°	22	90	Angle between direction of main line and current
13°	12	90	Angle between direction of main line and wind
0°	0	90	Angle between direction of main line and wave
3 Branch 51 m	2 Branch 50	3 Branch 88	Horizontal drift of main line (Branch meets the main line)
16 m	20	0	Horizontal drift of the middle point of main line
			Depth of connecting point (main line and branch line)
32(49) m	51(69)	51.8(69)	1
47(64) m	72.3(91)	75(89)	2
70(86) m	48(66)	82.5(98)	3
76.7(94) m	32(49)	75(89)	4
48(64) m		60(78)	5

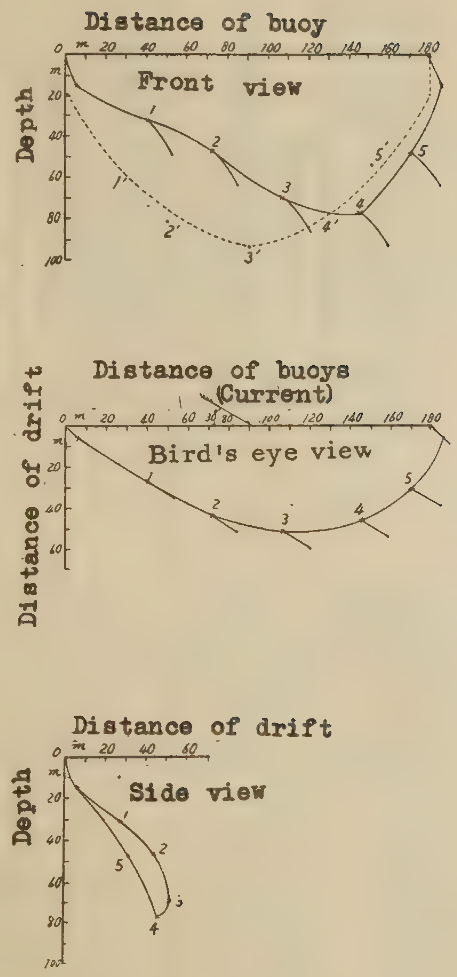

Fig. 1 Typical shape of the branches of the longline when bending before the water flow.

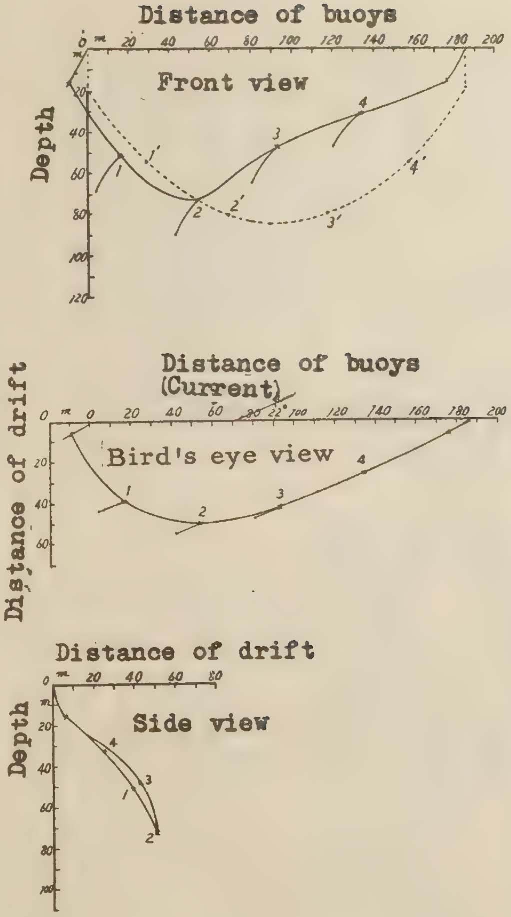

Fig. 2 Typical shape of the branches of the longline when bending before the water flow.

tinuous series of nets. The same principle can be applied to the tuna longline. The use of detecting devices on fishing grounds will help operators set lines horizontally within the favorable area, free of tension, at a desirable bearing, and at optimum depth.

3 BRANCH LINE MOVEMENT AND ITS HOOK RATE

Figs. 1 to 3 show the typical shapes of the branch lines when bending before the water flow. The branches join the main line at various angles, i.e., a branch nearest the upstream end of each basket bends closely parallel to the line, at a small angle, while the one farthest downstream keeps apart from the line, and forms a large angle. These angles are shown in Fig. 4, which illustrates samples of undesirable and desirable shapes in the branch lines. They play an important role in the hook rate, as shown in Fig. 5.

The hook rate is different for yellowfin tuna and albacore. This may be due to sensitivity of albacore toward the line, which is clearly noticed from the biting reaction, to which the author will refer later.

According to Fig. 4, the water flow and the branch line on the upstream end of each basket are in the same direction. Thus, the hook and the branch come close to the main line, causing the main line to hang over the baited hook.

The upper part of a branch line is made of flexible fiber rope, and the lower part is of stiff, steel wire. The upper part, eventually, bends before the water flow, while the lower part hangs vertically. The author considers that baited hooks fixed to vertical-hanging branches are less effective than hooks fixed to curving branches as shown in Fig. 6 - right.

In order to hang in ideal form, the branch line made of soft fiber should be replaced by hard wire, rather heavy in weight and of small diameter. The wire, which bears the hook conventionally covered with cotton yarn and attached to the upper part of the branch line should be replaced by light fiber rope. Both these changes will favor a smooth water flow. The wire bearing the hook should be made as short as is practicable.

If a fiber rope is used just above the hook, however, it may part when the tuna bites. Abrasion of the rope against the ship's bulwark must also be taken into consideration. If the branch is of hard wire of small diameter, it may be dangerous to handle with bare hands. These troubles, however, are conquered with the help of protecting gloves or, eventually, by means of hauling devices.

4 BITING PERIOD AND REACTION OF TUNA

It is said that most tuna bite twice: first, when baited hooks are descending following the setting of the line and again when the hooks are rising as the gear is hauled in. The author, however, has no data to support this supposition.

The experimental trial showed that albacore and marlin bit even after the main line had settled and reached a balance between the line itself and exterior effects such as water flow, etc. Therefore, as long as the gear is set in the water its fishing potential exists.

The behavior of fish caught on hooks differs according to the species. For example, an albacore tends to pull down the line, while a marlin tends to heave up the line (Fig. 7).

It is clear that the smaller albacore tries to the utmost to sink deeper, while the larger and stronger marlin spends but little energy on pulling up the line which remains light until the branch becomes taut. As a result of its strenuous diving an albacore loses its life in 10 minutes after biting.

5 RELATION BETWEEN WATER TEMPERATURE AND DEPTH OF HOOKED TUNA

Figs. 8 and 9 illustrate the relationship between water temperature, depth, and catch rate for yellowfin tuna and albacore. However, the author is not sure whether these data agree with the biologically optimum temperature for the fish.

In the field observations the temperature frequented by yellowfin centered around 22°-23°C, ranging from 18°-30°C. For albacore, it centered around 23°C, ranging from 16° to 29°C, while with marlin it centered around 23°-24°C, ranging from 18°-29°C. As these catches were dependent on certain branch shapes, the data cannot be applied to any other conditions.

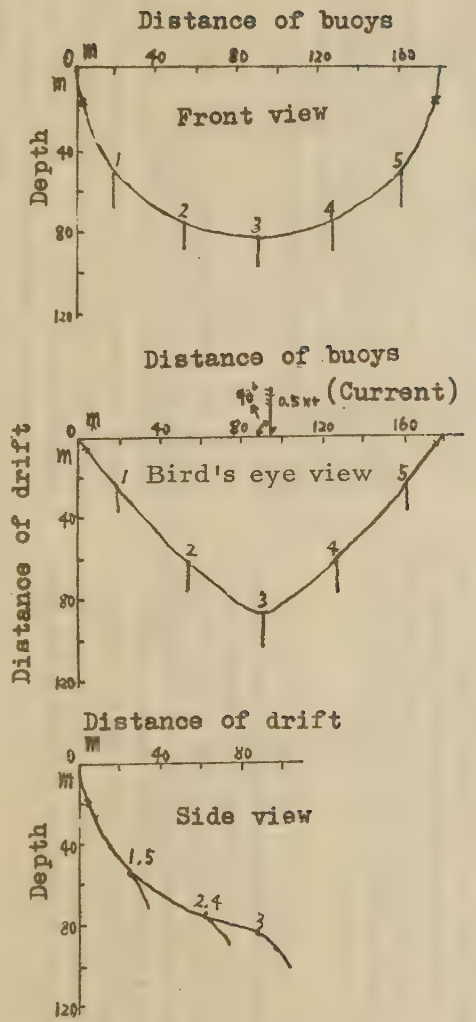

Fig. 3 Typical shape of the branches of the longline when bending before the water flow.

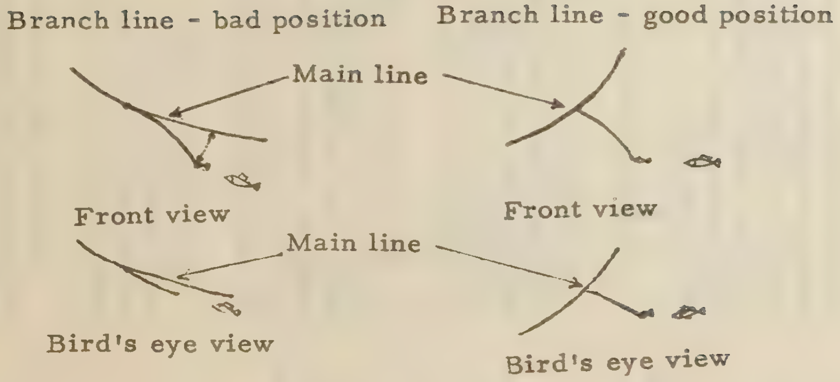
Branch line - bad position
Branch line - good position
Main line
Front view
Front view
Main line
Bird's eye view
Bird's eye view

Fig. 4 Longline and branch - good and bad positions.

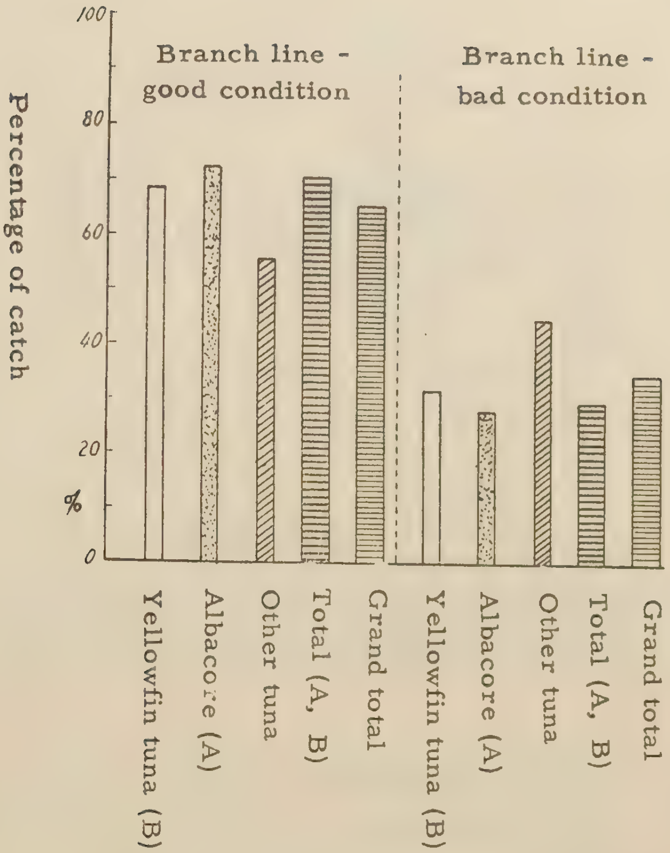

Fig. 5 Catch when branch in good and bad position.

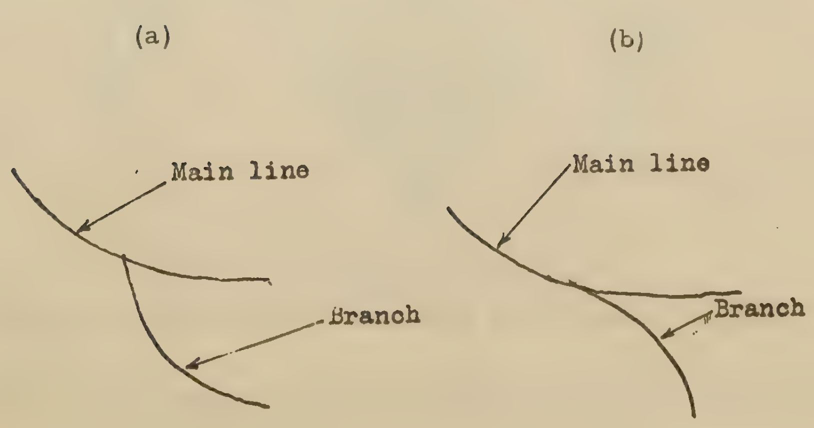
(a)
(b)
Main line
Branch
Main line
Branch

Fig. 6 Baited hooks fixed to vertical hanging (a), and bending curved hanging (b).

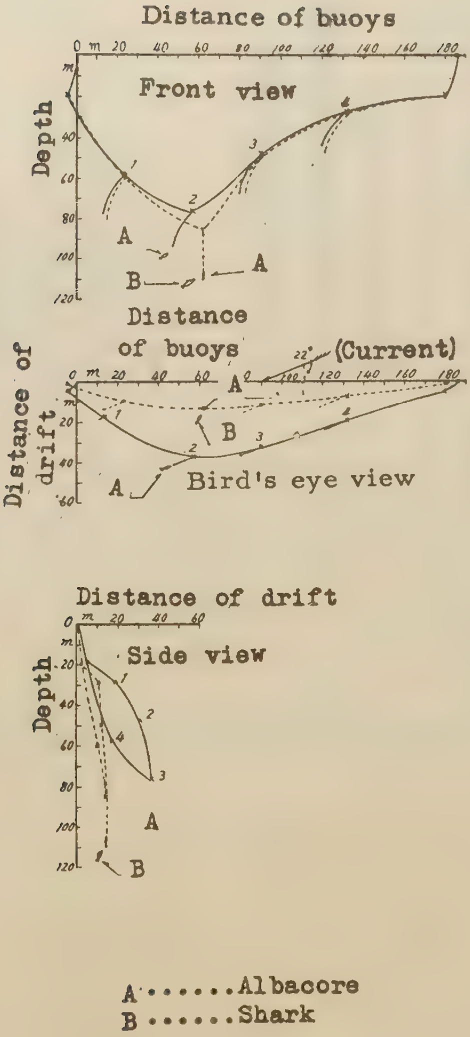

Fig. 7 Behavior of albacore and shark when hooked.

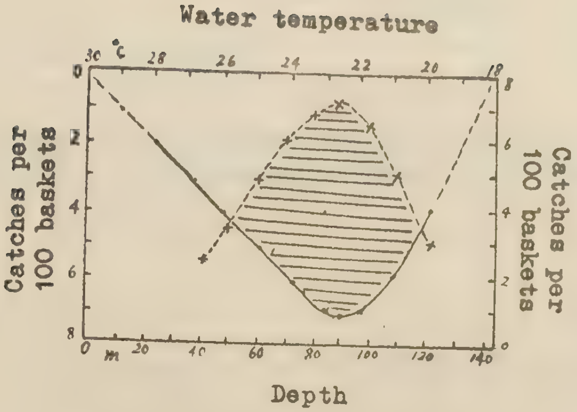

Fig. 8 Relationship between water temperature and depth of layers of yellowfin tuna and albacore.

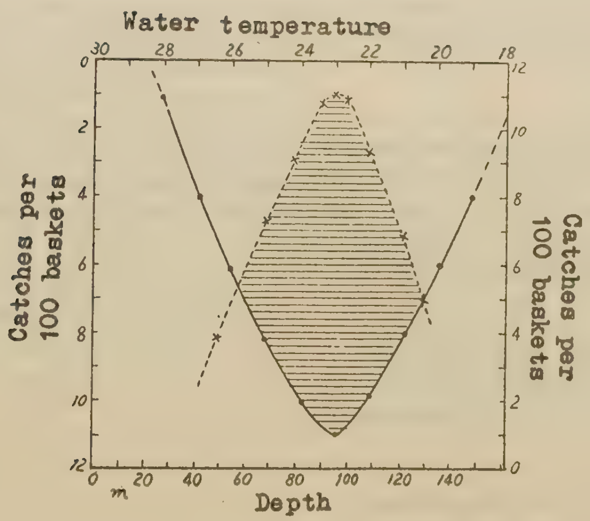

Fig. 9 Relationship between water temperature and depth of layers of yellowfin tuna and albacore.

Table II

Up and down motion of hooks originated by waves

Type of line	No. of branch line				
	1	2	3	4	5
Cotton 42 g in weight per 1 ft 5Br.	0.25 m	0.13-0.1 m		0.27 m	-
" 34 g in weight per 1 ft 4Br.	0.27 m	-	0.13-0.1 m	-	0.3 m
Kuremona (Dyed by coal-tar) 5Br.	0.26 m	-	0.13-0.1 m	-	0.27 m
" " " " 5Br.	0.27 m	-	0.13-0.1 m	-	0.27 m
Kuremona (Contains a lead line and resin finishing) 5Br.	0.27 m	-	0.13-0.1 m	-	0.27 m
Teviron 5Br.	0.3 m	-	0.13-0.1 m	-	0.27 m

Note: Wave height 0.5 m, Frequency 6 sec.
Cross angle (56°) between main line direction and waves

Whenever there is a known optimum temperature for the fish, baited hooks should be hung as far as possible, in the correct temperature zone. It is useless to fish outside the optimum temperature zone.

Development of the fish finder should make it possible to exploit fishing grounds more completely, and to carry out studies on control of hook depth and shapes of the longline.

6 INFLUENCE OF WAVES ON BEHAVIOR OF HOOKS

Surface waves tend to cause an up and down motion of the buoys. This motion is conveyed to the hook through the buoy line, main line and branch line respectively.

If the longline is made of light material with smooth water flow characteristics, the wave pulls up the gear to wave-height. Since lines do not sink swiftly because of their light weight, the current then deforms the slack parts of the gear. These factors tend to keep the lines nearer to the water surface. To avoid these defects, the material of the lines should have enough weight to sink comparatively fast the moment the buoys begin to descend.

Table II illustrates the up and down motion of hooks, originated by waves. The motion varies with the same wave, according to variations in the shape of the lines. The Table also shows that the branch fixed nearest to the buoy line moves in a wide motion. The movement is greatest when the lines have not assumed a marked curvature. The up and down motion seems to be absorbed in the bending curve of the line after the wave has passed.

Experience Paper No. 5

ESTUDIOS SOBRE LA REPRODUCCION DEL BONITO Sarda chilensis (C. y V.) EN AGUAS ADYACENTES A LA COSTA PERUANA

por

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Extracto

El bonito Sarda chilensis (Cuvier) en aguas peruanas, alcanza la madurez sexual en tallas que varían de 470 a 530 mm.

El monto mayor de su pesca comercial se compone de ejemplares sexualmente maduros. Su período de reproducción comprende de principios de primavera a fines de verano; la actividad sexual dura de 6 a 8 meses, con un ápice que varía entre 5 y 3 meses. La maduración no se produce simultáneamente en todos los ejemplares; parece existir una tendencia a que los más grandes maduren primero. El desove es fraccionado. Las hembras completamente maduras, en pleno desove, tuvieron una representación reducida en las muestras.

La proporción de machos a hembras, en las muestras, es alrededor de 1:1, aunque fluctúa en los diferentes grupos de tamaños. La cantidad de óvulos maduros producidos por hembra varía considerablemente, aunque en forma general está en razón directa a la talla. Los bonitos de 600 mm. de talla y peso de 3 kilos, que representan el promedio de los ejemplares que componen la pesca comercial, producen alrededor de medio millón de ovas en cada estación. No todos los óvulos producidos son desovados, los óvulos residuales degeneran y son reabsorbidos. La estimación de óvulos que elimina cada hembra por vez confirmaron la ocurrencia de varias puestas en la estación de desove.

STUDIES OF THE REPRODUCTION OF THE BONITO Sarda chilensis (C. and V.) IN PERUVIAN COASTAL WATERS

Abstract

Bonito Sarda chilensis (Cuvier) reaches sexual maturity in Peruvian waters at sizes between 470 to 530 mm. Such sexually mature specimens comprise most of the commercial fishery. Spawning occurs from the beginning of spring to the end of summer. It lasts six to eight months, with a peak varying from five to three months. Maturity is not simultaneous, but it seems larger specimens mature first. Spawning is fractionary. A small number of completely mature spawning females was found in the samples.

The sex ratio in the samples was about 1:1, but fluctuated with the different size groups. The quantity of ova varies considerably, but in general it is directly proportional to size of females. Bonitos 600 mm long weighing 3 kg, the average of the specimens commercially caught, produce about one-half million ova every spawning season. Not all ova are spawned. Residual ova degenerate and are reabsorbed. Estimates of the number of ova each female spawns during each spawning confirmed the occurrence of various spawnings during the spawning season.

ETUDE DE LA REPRODUCTION DE LA BONITE Sarda chilensis (C. et V.) DANS LES EAUX COTIERES PERUVIENNES

Résumé

Dans les eaux péruviennes, la bonite Sarda chilensis (Cuvier) atteint sa maturité sexuelle à une taille variant entre 470 et 530 mm. Le gros de la pêche commerciale porte sur des individus parvenus à ce stade. La reproduction a lieu du début du printemps à la fin de l'été. Elle dure de six à huit mois, avec un maximum allant de trois à cinq mois. La maturation n'est pas simultanée, et il semble que les individus de forte taille soient plus précoces. Le frai s'effectue en plusieurs fois. Les échantillons renfermaient peu de femelles adultes en période de ponte.

Dans les échantillons, le rapport entre les deux sexes était en moyenne d'environ 1:1, mais fluctuait suivant les groupes de tailles. Le nombre d'oeufs, très variable, est en général directement proportionnel à la taille des femelles. Les bonites de 600 mm. pesant 3 kg, moyenne des individus capturés par la pêche commerciale, produisent environ un demi-million d'oeufs durant chaque fraie. Ils ne sont pas tous pondus, et les oeufs résiduels dégénèrent et sont résorbés. Des estimations du nombre d'oeufs pondus par chaque femelle durant chaque fraie ont confirmé l'existence de pontes multiples au cours d'une période de reproduction.

1 INTRODUCCION

En los últimos años pasados se inició en la Dirección de Pesquería y Caza, en cooperación con el Consejo de Investigaciones Hidrobiológicas de Lima, Perú, un programa conducente al conocimiento de las características biológicas del bonito Sarda chilensis (Cuvier), uno de los peces de mayor importancia comercial en el Perú.

Este trabajo es uno de los que se realizaron en el desarrollo de dicho programa y detalla los hábitos de desove de esta especie.

2 MATERIAL Y METODOS

2.1 Material

El material básico para este estudio consistió en 1.078 ejemplares muestreados, consecutivamente, desde noviembre de 1957 a marzo de 1960, procedentes de la pesca comercial del área comprendida entre Chimbote (9°04' S, 78°35' O) e Ilo (17°38' S, 71°21' O), correspondiendo la mayor representación en estas muestras al puerto del Callao.

Las longitudes del total de estos ejemplares fluctuaron entre 207 y 715 mm., con un valor promedio de 580 mm.; de ellos, 565 fueron machos y los 513 restantes, hembras, correspondiendo más de las tres cuartas partes del material muestreado a ejemplares sexualmente maduros.

2.2 Métodos

La determinación del período de reproducción se efectuó por inspección macroscópica de las gónadas, índice de madurez expresado en la relación percentual peso gónada-peso cuerpo y medida del diámetro de los óvulos.

El tipo de desove fue determinado por la distribución de la frecuencia del diámetro de los óvulos dentro del ovario.

Se calculó además el número de óvulos, producidos por hembra, por el método gravimétrico.

3. DETERMINACION DEL CICLO SEXUAL

3.1 Tamaño de la primera madurez

En época de actividad sexual, la hembra más pequeña encontrada en curso de maduración medía 470 mm. de longitud a la horquilla; procedía de Ilo.

En las tallas inmediatamente superiores a ésta, se encontraron algunas hembras madurantes, y a partir de los 530 mm., todas las hembras fueron maduras. Es decir, que las tallas en que el bonito ingresa a cumplir el primer ciclo sexual oscilaban entre 470 y 530 mm.

Este tamaño de la primera madurez fijado correspondería a las hembras y no podemos asegurar que sea el mismo para los machos; pero sí podemos decir que todos los machos encontrados en las muestras a partir de los 540 mm. fueron maduros.

Como los bonitos que componen el grueso de la pesca comercial en el litoral fluctúan regularmente de 500 a 750 mm., el tamaño de la primera madurez fijado nos conduciría al criterio que estos bonitos son adultos.

3.2 Estación de desove

La estación de desove fue fijada por los resultados de los exámenes de madurez por los tres métodos indicados en 2.2, mostrándose los datos en promedios mensuales.

De acuerdo con estos resultados, se determinó un período de reproducción estacional que corresponde, en forma general, a los meses de mayor temperatura del año.

3.2.1 Examen macroscópico de gónadas

Las gónadas fueron examinadas y se les asignó un índice de actividad sexual de acuerdo con una escala patrón, Schaefer y Orange (1956) para la catalogación de ovarios, y Matsui (1942) modificada, para los testículos. Las equivalencias de la escala fueron:

Ovarios: 1.- Inmaduro; 2.- Maduración incipiente; 3.- Maduración avanzada; 4.- Maduro a desovado, y 4.- Evacuado.

Testículos: 1.- Inmaduro; 2.- Madurando; 3.- Maduro, y 5.- Evacuado.

La clasificación de las gónadas se muestra en las Figs. 1 y 2 que indican las de ovarios y testículos, respectivamente.

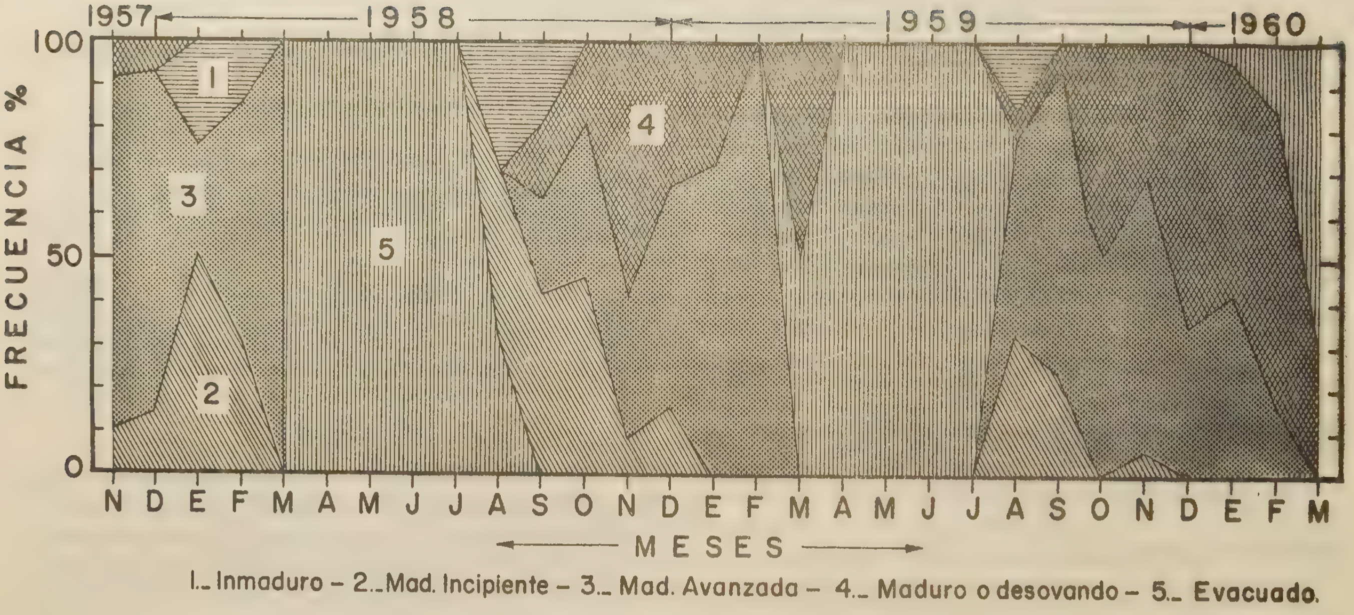

Fig. 1.- Frecuencia expresada en porcentaje de los estados de maduración durante el período noviembre 1957 - marzo 1960

Hembras.- Escala 1 a 5

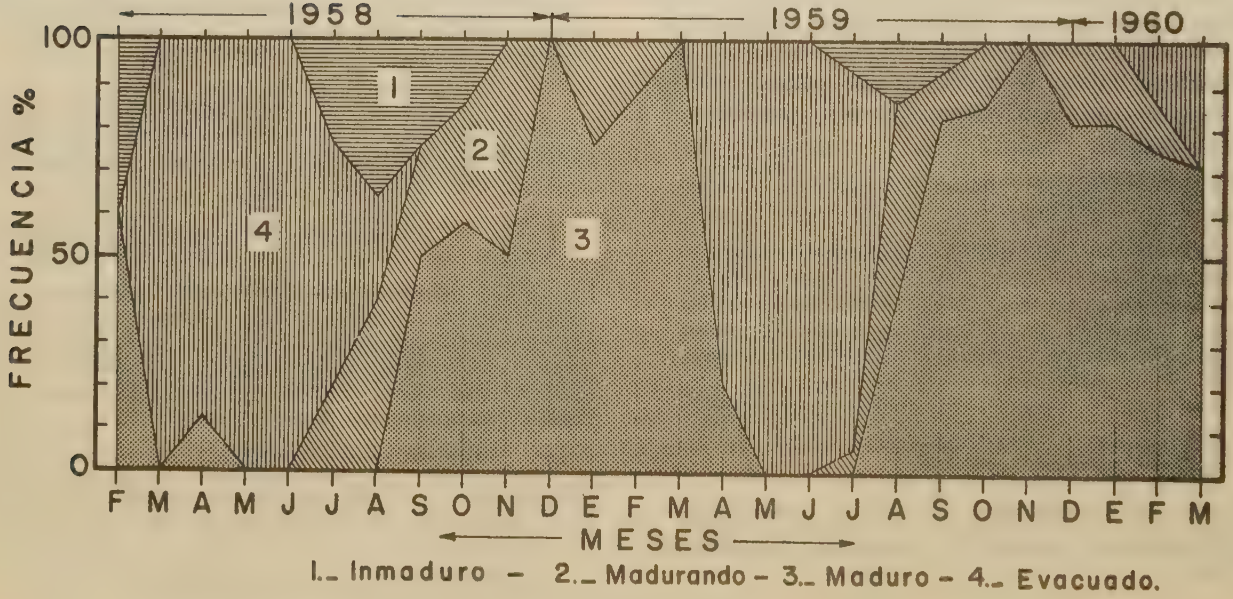

Fig. 2.- Frecuencia expresada en porcentaje de los estados de maduración durante el período febrero 1958 - marzo 1960

Machos.- Escala 1 a 4

La duración de las estaciones de desove, de acuerdo con la actividad sexual percibida macroscópicamente, puede resumirse de las tendencias reflejadas en la clasificación de los ovarios.

1957-58.- No se conoce cuándo principió; en noviembre, época en que comenzó el trabajo, la actividad gonadal estaba avanzada. Terminó en febrero.

1958-59.- Aunque en agosto de 1958 se notó un apreciable porcentaje de hembras madurantes, no consideramos exacto indicar ese mes como inicio de la temporada, porque en nuestras muestras figuran estas hembras registradas a fin del mes; por esta razón, la temporada se considera a partir de septiembre y abarcó hasta marzo, con el período principal de noviembre a enero.

1959-60.- Comprendió de agosto a marzo, con el período principal de octubre a febrero.

Los períodos señalados de desove fluctuaron en su extensión, indicándose como máxima duración, dentro del tiempo estudiado, la estación de desove de 1959 a 1960, con una amplitud de 8 meses.

Al mismo tiempo, el principal período dentro de esta estación se manifestó más prolongado que en las estaciones anteriores.

3.2.2 Indice de madurez

Los resultados de estas determinaciones en machos y hembras se expresan en la Fig. 3.

Los valores promedios más elevados, indicados en la figura aludida, se considerarían como índices de mayor actividad y los mínimos de absorción o reorganización de las gónadas, juzgando a los valores altos o bajos, de acuerdo con su proximidad a los valores promedios extremos.

De una manera general, a juzgar por nuestras observaciones, ejemplares con índices de madurez inferiores a 2%, señalarían una actividad sexual baja, incipiente o decadente, por encima de este valor y hasta con más o menos 4% una actividad moderada, incrementando o disminuyendo y superando este último valor, la actividad la consideramos de elevada a máxima, aunque hay que tener en mente que individuos recién desovados pueden conservar índices de madurez elevados.

Apreciando los resultados bajo esta base tenemos:

Los promedios mensuales de índice de madurez señalan inactividad de abril a julio; marzo y agosto actividad baja, y actividad continuada en los otros meses, con un ápice que varía de noviembre a enero, aproximadamente.

Los períodos de desove indicados por los valores del índice de madurez, en el lapso estudiado, son:

1957-58.- No se registró el inicio, se observaron valores altos en noviembre y diciembre; terminó en febrero.

1958-59.- Comprendió de septiembre a marzo, con su ápice de noviembre a enero.

1959-60.- Comprendió de agosto a marzo, con su ápice de octubre a febrero.

Es decir, se señalan períodos de actividad que comprenden hasta 8 meses, en el más prolongado. También se aprecia el adelanto de un mes, en el inicio de la temporada 1959-60, con respecto a la de 1958-59.

3.2.3 El diámetro de los óvulos

Para caracterizar las muestras de óvulos de cada ovario, se escogió en la distribución del total de las frecuencias de sus diámetros, el 95avo percentil, siguiendo el método de Schaefer y Orange (1956).

La maduración sexual mes a mes, la muestra la Fig. 4, con los promedios mensuales de los óvulos más desarrollados (95avo percentil) en las muestras correspondientes.

Considerando la secuencia de valores de diámetro de los óvulos expresados en el promedio mensual, como indicadores del período de desove, tendremos como extensión determinada de éste en el período estudiado:

1957-58.- No se observó el inicio de la temporada de desove; de acuerdo con la tendencia expresada en la figura 4, el ápice pareció corresponder a noviembre. Terminó en febrero.

1958-59.- Septiembre a marzo. El ápice correspondió a enero.

1959-60.- Principió en agosto y declinó en marzo.

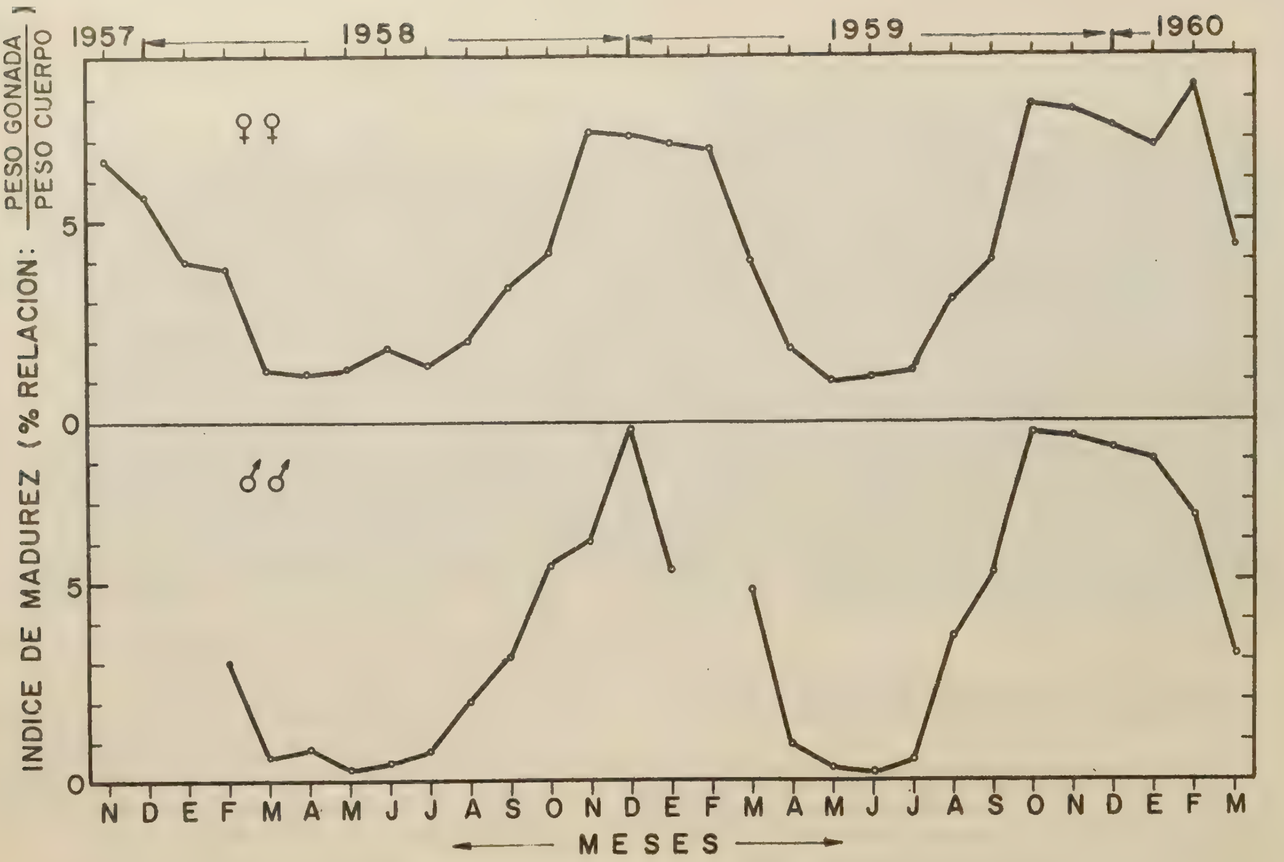

Fig. 3.- Fluctuaciones mensuales del valor promedio del Indice de Madurez en el período noviembre de 1957 - marzo de 1960

Panel superior: hembras; panel inferior: machos

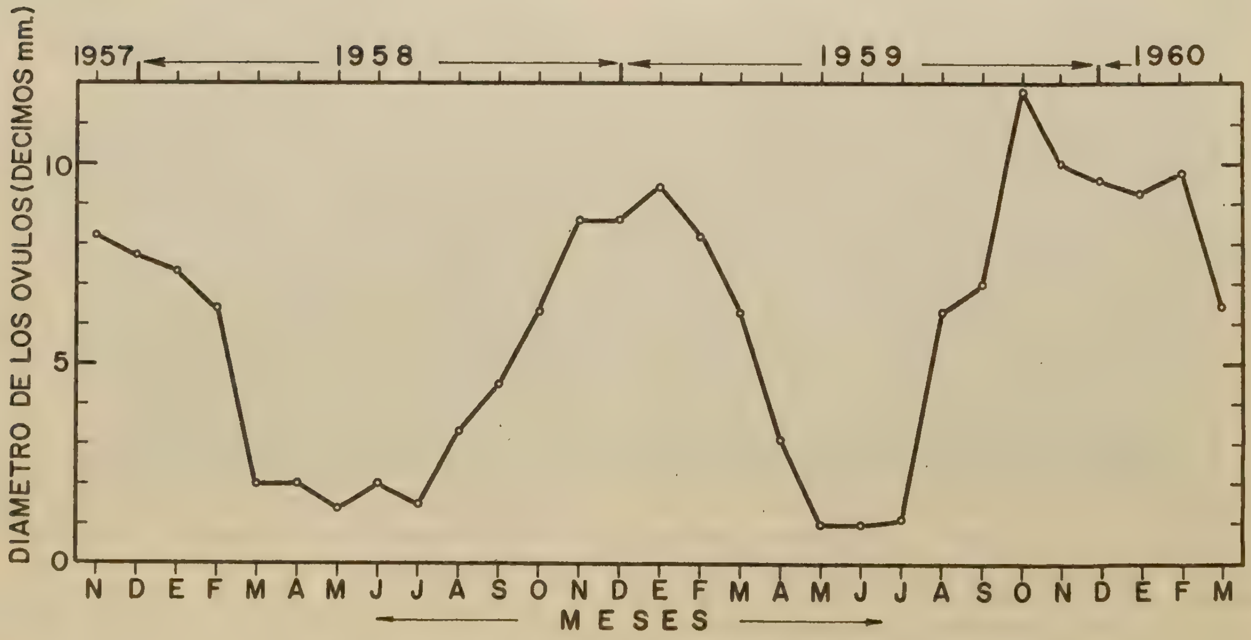

Fig. 4.- Fluctuaciones mensuales del valor promedio de los óvulos expresadas en el 95avo Noviembre de 1957 - marzo de 1960

La determinación de la actividad de los ovarios, por el método de medida del diámetro de los óvulos, señaló en el bonito los mismos períodos de desove fijados por los métodos anteriores, y que también concuerdan con los meses fijados de actividad sexual en Sarda chilensis, por otros autores como Schweigger (1959), Bini (1952), de Buen (1958), y Klawe (1961).

3.3 Diferencias encontradas durante el ciclo sexual con respecto a la talla y el sexo

3.3.1 Respecto a la talla

Dentro de las muestras de un mes y aún en las correspondientes a un día pueden encontrarse bonitos en varios estados de maduración; la observación de los estados sexuales, en diferentes grupos de tamaños, mostró la tendencia a que la maduración se produzca primero en los bonitos de mayor talla.

3.3.2 Respecto al sexo

1 La presencia de los productos gonadales maduros fue notada en los testículos con cierta anterioridad con respecto a los ovarios, y aparentemente tuvieron además una relativa persistencia en sus tejidos.

Las gónadas de los machos experimentaron mayores fluctuaciones de peso que las de las hembras, descendiendo, comparativamente, a pesos inferiores.

4 TIPO DE DESOVE

Fueron observadas las siguientes características:

(a) distribución ovárica polimodal, con la peculiaridad que cuando existen óvulos maduros en el lumen también se aprecian externamente.

(b) Terminada la época de la puesta, sólo se encuentran en el ovario ovocitos jóvenes.

(c) Los ovocitos madurantes son utilizados sucesivamente, dentro del tiempo de la estación de desove de cada individuo, hecho que fue demostrado siguiendo los procedimientos de Clark (1934) para detectar en el individuo el desarrollo de ovulos destinados a ser eliminados sucesivamente, y que se demuestran en las Figs. Nos. 5, 6 y 7, que corresponden a las estaciones de puestas sucesivas de 1957-58, 1958-59 y 1959-60.

En cada una de estas estaciones, se ha considerado la distribución percentílica promedio, dividida en grupos que van en orden correlativo de A a M, según que la localización del modo de los ejemplares, agrupados según la medida del diámetro de sus óvulos que poseen, esté entre 1/10 hasta 13/10 mm., con intervalos de 1/10 de mm.

El análisis de estas figuras muestran una muy clara correlación, entre el crecimiento de estos sucesivos grupos de óvulos. En efecto, observamos que, a medida que los ovarios maduran, los óvulos mayores constituyen un modo y en posterior desarrollo surge un segundo modo de óvulos menores. En estos modos secundarios se aprecia la tendencia a una progresión, que demostraría que una segunda agrupación madura paralelamente a la del grupo madurante mayor.

(d) Ocurrencia en el ovario, con relativa frecuencia de óvulos degenerados, entremezclados con otros maduros y madurantes.

Todas las características anotadas, respaldarían la sugerencia que el bonito Sarda chilensis se caracteriza por tener un desove fraccionado, pero uniforme y continuo.

Como una consecuencia de este tipo de desove, el período de reproducción es prolongado.

Además, no todos los óvulos existentes han de ser evacuados; existe una fracción de ellos cuyo destino es ser reabsorbidos o degenerados.

5 PRESENCIA DE LOS DESOVADORES EN LA PESQUERIA

En los períodos de desove que se han señalado, que comprenden los meses de primavera y verano, las hembras de bonito encontradas en pleno desove, no fueron muy abundantes en las muestras.

De acuerdo con el examen macroscópico de gónadas, ellas comprendieron el 4, 3%. Ejemplares hembras que tuvieron índices de

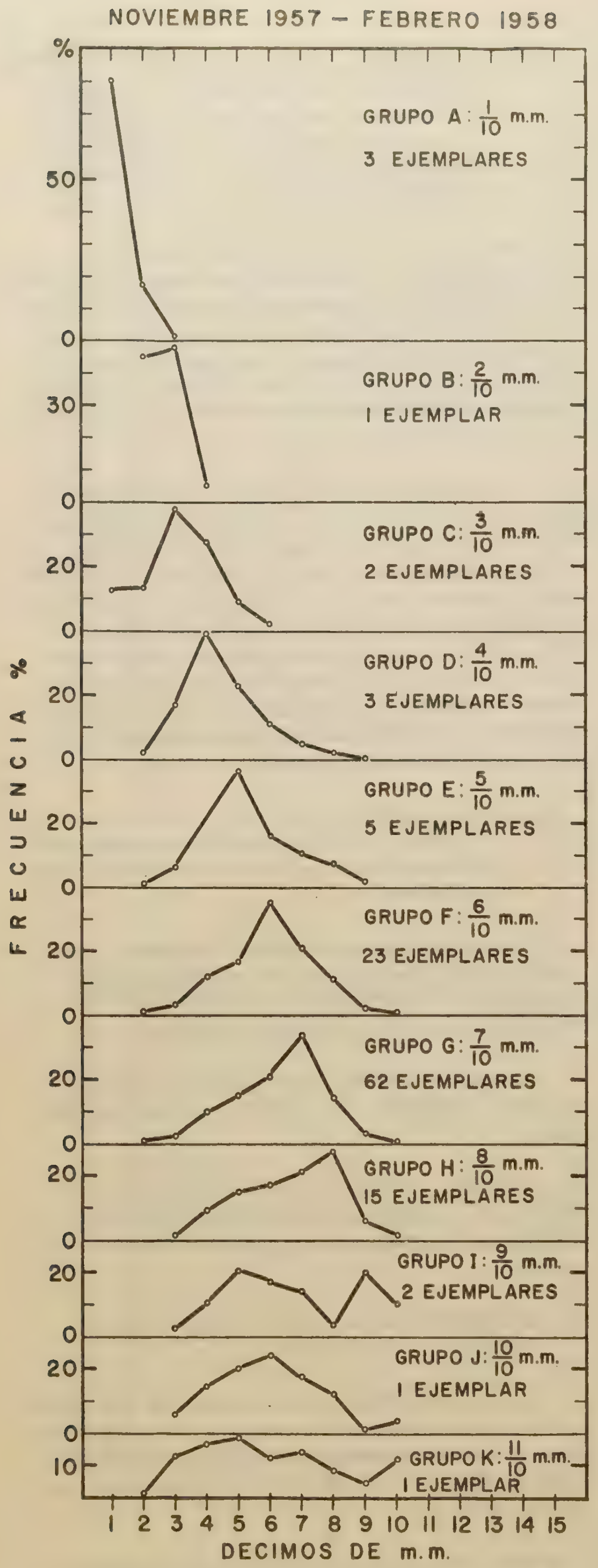

Fig. 5.- Distribución percentílica promedio de las medidas de óvulos correspondientes a todas las hembras catalogadas en actividad sexual de noviembre de 1957 a febrero de 1958, agrupados de acuerdo con la posición del último modo. Intervalo de un décimo de milímetro.

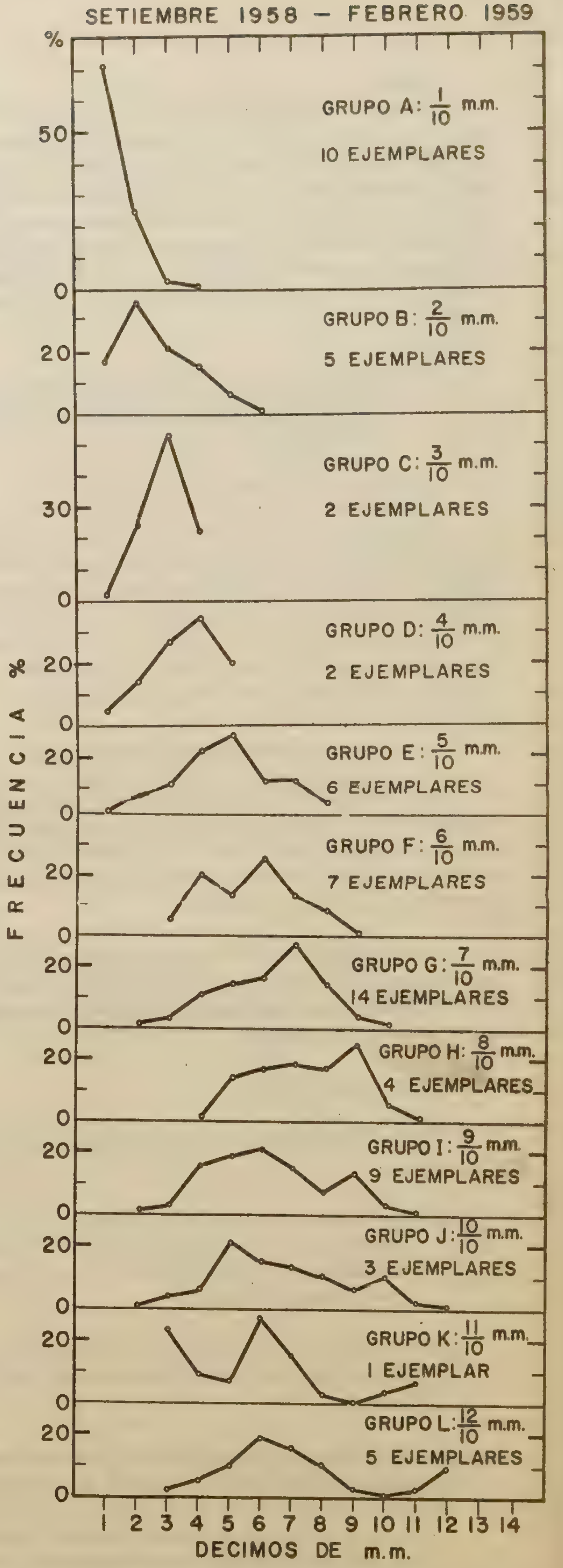

Fig. 6.- Distribución percentílica promedio de las medidas de óvulos correspondientes a las hembras catalogadas en actividad sexual de septiembre de 1958 a febrero de agrupados de acuerdo con la posición del último modo. Intervalo de un décimo de milímetro.

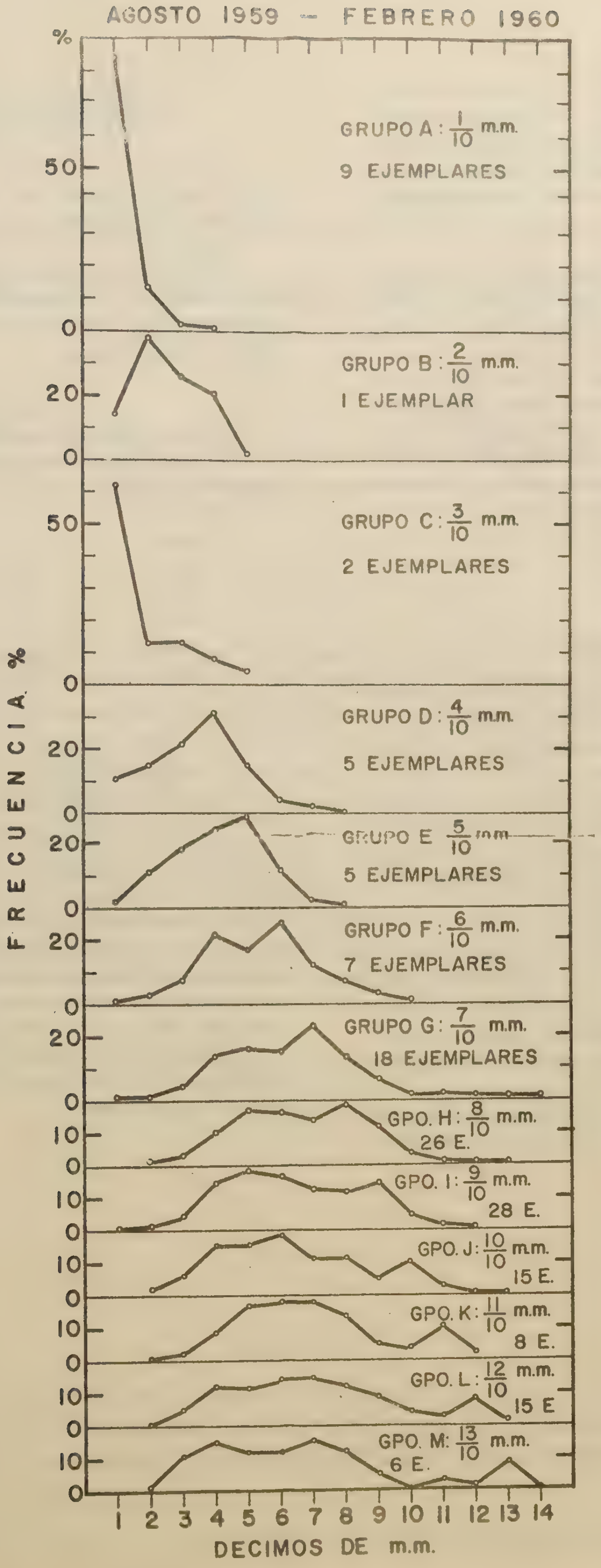

Fig. 7.- Distribución percentílica promedio de las medidas de óvulos correspondientes a todas las hembras catalogadas en actividad sexual de agosto de 1959 a febrero de 1960, agrupados de acuerdo con la posición del último modo. Intervalo de un décimo de milímetro.

madurez tan elevados como los de aquéllos encontrados en pleno desove, representaron en conjunto el 17% del total de hembras muestreadas, en los períodos de reproducción; éstas pudieron indicar también desoves recientemente efectuados.

La medida de diámetro de los óvulos señaló que los ovarios, que poseían óvulos maduros, representaron hasta el 24, 9% de las muestras. Estos valores de los diámetros de sus óvulos encontrados podrían ser tomados como indicio de un desove próximo, realizándose o recientemente efectuado. Este hecho, de la menor frecuencia de los desovadores en las muestras, es también constatado en otros escómbridos, así como en anchovetas y sardinas, y podría deberse a causales diversas.

6 FECUNDIDAD

6.1 Proporción de sexos

La proporción de sexos en el total de las muestras fue: machos, 52, 4%, y hembras, 47, 6%; es decir, aproximadamente el 50% para cada uno.

Al dividir el material para su análisis, los machos y las hembras inferiores a 500 mm. que por su talla corresponden a juveniles, se mostraron en proporción de 1:1.

En cuanto a los ejemplares de 500 mm. y superiores, es decir, los adultos, mostraron una tendencia a una mayor proporción numérica de los machos, aún cuando esta tendencia no pareció estar conectada a cambios estacionales.

Sin embargo, estas apreciaciones no tienen un carácter definitivo, dadas las caracterísiticas de las muestras.

6.2 Estimación del número de óvulos producidos por hembra

El número de óvulos producidos por hembra los encontramos en razón directa al aumento de longitud y peso.

Al efectuar el cálculo del número de óvulos producidos, de acuerdo con la longitud, por el método de cuadrados mínimos, obtuvimos el siguiente resultado:

Cuadro I
Estimación de cantidades de óvulos
por regresión de longitudes

Long. (mm.)	Miles de óvulos
500	288, 2
550	413, 3
600	754, 2
650	771, 1
700	1.028, 4
750	1.334, 8

6.3 Estimación de óvulos que elimina cada hembra por vez

Entre los ovarios más avanzados en su maduración se encontró que 12 mostraban una fracción de sus óvulos listos a ser evacuados; ésta variaba entre el 1, 8 y el 16% en el peso de la masa total de los ovarios. Es probable que esta proporción no exprese la máxima cantidad de óvulos que pueden ser eliminados por vez; pero por las relaciones que ellos guardan con la producción estimada de óvulos por hembra, confirman la ocurrencia de varias puestas en la estación de desove.

Experience Paper No. 6

TUNAS (genus Thunnus) OF THE WESTERN NORTH ATLANTIC[1]

Part I. Key to the species of Thunnus based on skeletal and visceral anatomy[2]

by

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Abstract

The genus Thunnus, comprising six species, possesses 39 vertebrae - the first of which is no more than half as long as the second. This characteristic separates genus Thunnus from all other known genera without exception, and it can be diagnosed by soft-X-ray photographs in specimens as small as 9 mm fork length. T. thynnus, T. alalunga and T. obesus form Group I whose diagnostic features are recognizably different from those in Group II containing T. albacares, T. atlanticus (found only in the Atlantic) and T. tonggol (found only in the Pacific). Each group is then analyzed for specific differences within the group. The key formulated is useful for ready identification of species, either by X-ray photographs or by examination of the abdominal cavity and gill rakers. Species differences apply to individuals 20 cm or longer in fork length. T. tonggol is proposed as the correct name for T. argentivittatus (MNHN A5814, Rivas 1961) supported by skeletal, visceral and external evidence.

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[1] The complete text of this paper will be published in the Proceedings of the Symposium on Scombroid Fishes, held by the Marine Biological Association of India at Mandapam Camp, India, 12 - 15 January 1962

[2] Contribution No. 1256 from the Woods Hole Oceanographic Institution

EP/6

LES THONS (genre Thunnus) DE LA PARTIE OUEST DE L'ATLANTIQUE NORD

Ière partie. - Classification des espèces du genre Thunnus d'après l'examen du squelette et des viscères

Résumé

Les poissons du genre Thunnus, qui comprend six espèces, possèdent 39 vertèbres - la longueur de la première ne dépassant pas la moitié de celle de la seconde. Cette caractéristique distingue le genre Thunnus de tous les autres genres sans exception, et peut être décelée par la radiographie aux rayons mous chez des individus ne mesurant pas plus de 9 mm (longueur à la fourche). Le groupe I réunit les espèces T. thynnus, T. alalunga et T. obesus, dont les caractéristiques sont nettement différentes de celles des espèces du groupe II: T. albacares, T. atlanticus (ne se trouvant que dans l'Atlantique) et T. tonggol (ne se trouvant que dans le Pacifique). Chaque groupe est étudié en vue de déceler des différences spécifiques entre espèces. La clef fournie par le document permet d'identifier rapidement les espèces, soit par radiographie, soit par examen de la cavité abdominale et des branchiospines. Les différences entre espèces sont sensibles chez les individus mesurant au moins 20 cm à la fourche. En s'appuyant sur les caractères extérieurs ainsi que sur l'examen du squelette et des viscères, il est proposé de désigner le T. argentivittatus (MNHN A5814, Rivas 1961) du nom exact de T. tonggol.

ATUNES (género Thunnus) DEL ATLANTICO NOROCCIDENTAL

Parte I. Clave para identificación de las especies de Thunnus basada en la anatomía del esqueleto y de las vísceras

Extracto

El género Thunnus, que comprende seis especies, posee 39 vértebras, la primera de las cuales tiene una longitud no mayor de la mitad de la segunda. Esta característica diferencia sin ninguna excepción al género Thunnus de todos los demás géneros conocidos y puede ser establecida mediante fotografías radiográficas en ejemplares que tengan una longitud de la horquilla incluso de sólo 9 mm. T. Thynnus, T. alalunga y T. obesus forman el Grupo I, cuyas características de identificación son claramente diferentes de las del grupo II, que abarca T. albacares, T. atlanticus (que aparece sólo en el Atlántico) y T. tonggol (que se encuentra sólo en el Pacífico). A continuación se analiza cada grupo para establecer las diferencias específicas dentro del mismo. La clave formulada es útil para la rápida identificación de las especies, ya sea mediante fotografías radiográficas o mediante el examen de la cavidad abdominal y de las branquispinas. Las diferencias de las especies se aplican a individuos con una horquilla de longitud de 20 cm. o mayor. Se propone T. tonggol como nombre correcto para T. argentivittatus (MNHN A5814, Rivas 1961) basándose en las características del esqueleto de las visceras y externas.

EP/7

Experience Paper No. 7

TUNAS (genus Thunnus) OF THE WESTERN NORTH ATLANTIC [1]

Part II. Description, comparison and identification of species of Thunnus based on external characters [2]

by

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Abstract

Morphometric and meristic data and color notes were obtained for numerous specimens comprisng graded series covering the range of sizes available for each of the five species of Thunnus occurring in the western North Atlantic. These are the bluefin tuna, T. thynnus, the yellowfin tuna, T. albacares, the albacore, T. alalunga, the blackfin tuna T. atlanticus, and the bigeye tuna, T. obesus. Proportions, counts, and color descriptions are presented for the genus as a whole. The respective species are compared with emphasis on allometric development. Characters important for identification include the count of gill rakers, the lengths of the pectoral fins, the head, and the second dorsal lobe, the maximum depth, and the diameter of the iris. The head and anterior portion of the body become relatively shorter with growth, whereas the posterior portion of the body and the second dorsal, anal and caudal fins become relatively longer. The first dorsal and ventral fins remain relatively unchanged, and the pectoral, except in T. alalunga, is at its maximum relative size in medium-sized individuals of the respective species. Color characters important for identification include the white posterior edge of the caudal fin of T. alalunga, and the absence of yellow in the finlets of live T. atlanticus. A key for the identification of Thunnus species of the western North Atlantic based on external characters is presented. A preliminary comparison indicates that bluefin tuna of the eastern and western Atlantic differ from each other at the racial level at the most, and from those of the eastern Pacific at the subspecific level. Examinations of albacore from opposite sides of the Atlantic reveal no distinct morphological differences. Length frequencies of samples from the two regions indicate a distinct size segregation, with large individuals to the west and small ones to the east, possibly all belonging to one population.

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[1] The complete text of this paper will be published in the Proceedings of the Symposium on Scombroid Fishes, held by the Marine Biological Association of India at Mandapam Camp, India, 12 - 15 January 1962

[2] Contribution No. 1257 from the Woods Hole Oceanographic Institution

LES THONS (genre Thunnus) DE LA PARTIE OUEST DE L'ATLANTIQUE NORD

IIème partie. Description, comparaison et identification des espèces de Thunnus d'après les caractères extérieurs

Résumé

L'étude des caractères morphométriques et méristiques ainsi que de la coloration a été faite sur de nombreux individus classés par groupes représentant toute la gamme des tailles pour chacune des cinq espèces de Thunnus de la partie ouest de l'Atlantique Nord, à savoir : thon rouge (T. thynnus), thon à nageoires jaunes (T. albacares), germon (T. alalunga), 'thon noir' (T. atlanticus) et thon obèse (T. obesus). Les données relatives aux proportions, aux caractères numériques et à la coloration concernent l'ensemble du genre. La comparaison entre espèces accorde une grande place à l'allométrie. Parmi les caractères importants du point de vue de l'identification figurent le nombre des branchiospines, la longueur des nageoires pectorales, de la tête et de la seconde dorsale, la hauteur maximale, et le diamètre de l'iris. A mesure que croît la taille du poisson, la tête et la partie antérieure du corps deviennent comparativement plus courtes, l'inverse se produisant pour la partie postérieure ainsi que pour la seconde dorsale, l'anale et la caudale. La première dorsale et les abdominales demeurent relativement inchangées, et les pectorales, sauf chez T. alalunga, atteignent leur taille relative maximale, pour chaque espèce, chez les individus de longueur moyenne. Certaines caractéristiques de coloration importantes pour l'identification sont, chez T. alalunga, le bord postérieur blanc de la caudale, et, chez T. atlanticus vivant, l'absence de jaune sur les pinnules. Le document renferme, pour l'identification des espèces de Thunnus de la partie ouest de l'Atlantique Nord, une formule fondée sur les caractères extérieurs. D'après une comparaison préliminaire, les thons rouges des parties est et ouest de l'Atlantique diffèrent entre eux au maximum au niveau de la race, tandis qu'ils diffèrent de ceux de la partie est du Pacifique au niveau de la sous-espèce. Après examen, on n'a pas constaté de nettes différences morphologiques entre des germons provenant de parties opposées de l'Atlantique. La composition par groupes de taille des échantillons recueillis dans les deux régions révèle une nette séparation selon la grosseur : les individus de grande taille se trouvent à l'ouest et ceux de petite taille à l'est, mais ils appartiennent peut-être à la même population.

ATUNES (género Thunnus) DEL ATLANTICO NOROCCIDENTAL

Parte II. Descripción, comparación e identificación de las especies de Thunnus a base de las características externas

Resumen

Se obtuvieron datos morfométricos y merísticos y notas sobre coloración de numerosos ejemplares, incluídas series graduadas que abarcaban la escala de tamaños correspondiente a cada una de las cinco especies de Thunnus que se encuentran en el Atlántico noroccidental. Son éstas: el atún de aleta azul, *T. thynnus*; el atún de aleta amarilla, *T. albacares*; la albacora, *T. alalunga*; el atún de aleta negra, *T. atlanticus*, y el patudo, *T. obessus*. Se presentan proporciones, recuentos y descripciones de color para la totalidad del género. Se comparan las respectivas especies atendiendo principalmente a la evolución alométrica. Entre las caracteristicas importantes para la identificación figuran el cómputo de las branquispinas, las longitudes de las aletas pectorales, de la cabeza y del segundo lóbulo dorsal, la altura máxima, y el diámetro del iris. La cabeza y la porción anterior del cuerpo se hacen relativamente más cortas al aumentar el tamaño de los ejemplares, en tanto que la porción posterior del cuerpo y las aletas segunda dorsal, anal y caudal, se hacen relativamente más largas. La primera dorsal y la ventral permanecen relativamente sin variación y la pectoral, excepto en *T. alalunga*, alcanza su máximo tamaño relativo en individuos de talla media de la especie respectiva. Entre las características de color interesantes para la identificación se encuentran el borde blanco posterior de la aleta caudal de *T. alalunga* y la falta de coloración amarilla en las pínulas de *T. atlanticus* vivo. Se presenta una clave para la identificación de las especies de Thunnus del Atlántico noroccidental basada en las características externas. Una comparación preliminar señala que el atún de aleta amarilla del Atlántico oriental y el del occidental difieren entre sí como máximo, al nivel racial, y de los del Pacífico oriental al nivel de las subespecies. El examen de albacoras de uno y otro lado del Atlántico no revela diferencias morfológicas evidentes. Las frecuencias de longitud de las muestras de las dos regiones indican una distinta segregación por tamaños, con ejemplares grandes al oeste y pequeños al este, perteneciendo probablemente todos a una sola población.

TUNAS (genus Thunnus) OF THE WESTERN NORTH ATLANTIC [1]

Part III. Distribution and behavior of Thunnus species [2]

by

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Abstract

Three cosmopolitan species of Thunnus, the yellowfin tuna, T. albacares, the albacore, T. alalunga, and the bigeye tuna, T. obesus, are found over most of the warmer waters of the western North Atlantic. All three species are taken by longline fishing in oceanic waters at depths of from 15 to 100 fathoms throughout the year. During the warm months, they expand their range northward and into the waters of the continental slopes and shelves, retreating to the deeper waters in the late fall. T. albacares is the most sensitive to cold water, not being found north of the Gulf Stream except in the warmest period. Unlike the albacore and the bigeye tuna, it is frequently found at the surface. T. obesus and T. alalunga have not been recorded from the Gulf of Mexico, nor has the latter been taken in the Straits of Florida. The blackfin tuna, T. atlanticus, is apparently a local species restricted to the warmer waters of the western Atlantic, and, except in the Gulf of Mexico and the Caribbean Sea, is rarely taken by deep fishing. Its range expands but little in the warm months, rarely extending north of Cape Hatteras and Bermuda. The bluefin tuna, T. thynnus, is the most migratory species of the genus. Apparently nearly all the western North Atlantic population spends the warm months on the continental shelf from Cape Hatteras to Newfoundland, with the smaller individuals mainly to the southwest and the larger ones to the northeast. During the winter the species leaves the continental shelf and disperses widely over the subsurface waters of the Atlantic. Few of those weighing less than 120 kg, excepting small juveniles, have been taken south of 36°N, but the larger individuals range all the way to the Greater Antilles, the Gulf of Mexico, and the northwestern Caribbean Sea. Many schools of large T. thynnus regularly migrate northward through the Straits of Florida by the northwestern Bahamas in May and early June. Despite indications of a resident western North Atlantic population, both large and small bluefin tuna tagged in these waters have been recaptured off the coasts of Europe.

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[1] The complete text of this paper will be published in the Proceedings of the Symposium on Scombroid Fishes, held by the Marine Biological Association of India at Mandapam Camp, India, 12 - 15 January 1962

[2] Contribution No. 1258 from Woods Hole Oceanographic Institution

LES THONS (genre Thunnus) DE LA PARTIE OUEST DE L'ATLANTIQUE NORD

IIIème partie. Répartition et comportement de certaines espèces de Thunnus.

Résumé

On trouve dans la plupart des eaux chaudes de la partie ouest de l'Atlantique Nord trois espèces cosmopolites de Thunnus: le thon à nageoires jaunes (T. albacares), le germon (T. alalunga) et le thon obèse (T. obesus). Ces trois poissons se pêchent toute l'année aux palangres à des profondeurs allant de 15 à 100 brasses. Pendant les mois chauds, ils se déplacent vers le nord et gagnent les eaux du talus et du plateau continentaux pour se retirer en eau plus profonde à la fin de l'automne. T. albacares est le plus sensible aux basses températures, et on ne le trouve au nord du Gulf Stream que durant la saison chaude. A la différence du germon et du thon obèse, on le trouve souvent à la surface. T. obesus et T. alalunga n'ont pas été signalés dans le golfe du Mexique, et cette dernière espèce n'a jamais été capturée dans le canal de Floride. Le "thon noir" (T. atlanticus) est apparemment une espèce locale dont l'habitat est limité aux eaux chaudes de l'Atlantique Ouest; on le prend rarement en eau profonde, sauf dans le golfe du Mexique et dans la mer des Antilles Sa répartition géographique ne connaît qu'une faible extension durant les mois chauds, allant rarement au nord du cap Hatteras et des Bermudes Le thon rouge (T. thynnus) est l'espèce la plus migratoire du genre. Il semble que la quasi-totalité de la population de la partie ouest de l'Atlantique Nord passe les mois d'été sur le plateau continental, entre le cap Hatteras et Terre-Neuve, les individus de petite taille se tenant surtout au sud-ouest et ceux de grande taille au nord-est. En hiver, les poissons de cette espèce quittent le plateau continental et se dispersent dans tout l'Atlantique, où ils fréquentent les couches superficielles. On a rarement capturé au sud du 36ème parallèle Nord de thons rouges d'un poids inférieur à 120 kg, à l'exception de jeunes de petite taille, tandis que les individus plus gros ont été signalés jusqu'aux Grandes Antilles, au golfe du Mexique et dans la partie nord-ouest de la mer des Antilles. En mai et au début de juin, de nombreux bancs de T. thynnus de forte taille effectuent une migration régulière en direction du nord par le canal de Floride, passant au nord-ouest des Bahamas. D'après certains indices, il existerait dans l'ouest de l'Atlantique Nord une population permanente, mais des thons rouges, grands et petits, marqués et libérés dans ces eaux ont été recapturés au large des côtes européennes.

ATUNES (género Thunnus) DEL ATLANTICO NOROCCIDENTAL

PARTE III. Distribución y comportamiento de las especies de Thunnus.

Extracto

En casi todas las aguas más templadas del Atlántico noroccidental se encuentran tres especies cosmopolitanas de Thunnus: el atún de aleta amarilla, T. albacares, la albacora, T. alalunga, y el patudo, T. obesus. Las tres especies son capturadas con currican todo el año en aguas oceánicas a profundidades comprendidas entre 15 y 100 brazas. En los meses cálidos, amplían su área de distribución más al norte y a las aguas de los taludes y planicies continentales, retirándose a las aguas más profundas a finales de otoño. T. albacares es el más sensible al agua fría, no encontrándoselo al norte de la Corriente del Golfo (Gulf Stream) excepto en el período más cálido. A diferencia de la albacora y del patudo, se le encuentra con frecuencia en la superficie. T. obesus y T. alalunga no han sido registrados más allá del Golfo de México, el último tampoco ha sido capturado en el Estrecho de Florida. El atún de aleta negra, T. atlanticus es, al parecer, una especie local limitada a las aguas más templadas del Atlántico occidental y, salvo en el Golfo de México y en el Mar Caribe, es raramente capturado en la pesca de profundidad. Su área de distribución se amplía, aunque poco, en los meses de calor y rara vez se extiende al norte del Cabo Hatteras y de las Bermudas. El atún de aleta azul, T. thynnus, es la especie más migratoria del género. Al parecer, casi toda la población del Atlántico noroccidental pasa los meses cálidos en la planicie continental desde Cabo Hatteras a Terranova, distribuyéndose los individuos de menor tamaño principalmente hacia el sudoeste y los mayores hacia el nordeste. Durante el invierno esta especie abandona la planicie continental y se dispersa ampliamente bajo las aguas subsuperficiales del Atlántico. Al sur de 36° N., han sido capturados pocos individuos con un peso inferior a 120 Kg., salvo tratándose de formas juveniles, pero los ejemplares mayores se distribuyen en toda la extensión hasta las Grandes Antillas, el Golfo de México y la parte noroccidental del Mar de las Antillas. Muchos cardúmenes de grandes T. thynnus emigran regularmente hacia el norte, a través del Estrecho de la Florida, a lo largo de la parte noroeste de las Bahamas en mayo y principios de junio. A pesar de las indicaciones de la existencia de una población residente en el Atlántico noroccidental, ejemplares de atún de aleta azul marcados en dichas aguas, lo mismo de gran tamaño que pequeños, han sido recapturados en aguas de las costas de Europa.

Experience Paper No. 9

AN OUTLINE OF THE TUNA LONGLINE GROUNDS IN THE INDO-PACIFIC (PRELIMINARY REPORT)

By

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Kochi, Japan

Abstract

An outline of Japanese tuna longline vessels in the Indo-Pacific and of productivity of the fishing ground is given on the basis of the most recent data.

(a) The total landings in 1960 were about 360, 000 tons, comprising three parts tunas and one part other fish, the latter being composed of one-half marlins and one-half sharks.

(b) The number of sets per day in the entire Indo-Pacific is estimated to be about 360. The most concentrated operation occurs in the western North Pacific and the western Equatorial Pacific.

(c) Highly productive areas as longline grounds are in the equatorial regions of both the Oceans and in the westerly wind drift of the southern hemisphere. Each region has its own type of seasonal change in productivity of tunas and marlins and of species composition in catch.

(d) In order to understand the characteristics of the fishing grounds, it seems effective to introduce the "ecosystem" concept. Moreover, it is likely that the mechanism of fish aggregation within each ecosystem strongly reflects the life form of each species.

LIEUX DE PÊCHE DU THON AUX PALANGRES DANS LA REGION INDO-PACIFIQUE

(rapport préliminaire)

Résumé

Le document étudie les opérations des thoniers-palangriers japonais dans la région indo-pacifique et la productivité des lieux de pêche sur la base des données les plus récentes.

(a) En 1960, le total des quantités débarquées était de l'ordre de 360 000 tonnes, composées pour les trois quarts de thons, le reste se subdivisant également entre marlins et requins.

(b) Pour l'ensemble de la région, le nombre de lignes posées chaque jour est évalué à environ 360. C'est dans la partie ouest du Pacifique Nord et dans la partie ouest du Pacifique équatorial que la pêche est la plus intense.

(c) Les lieux de pêche aux palangres d'une productivité élevée se trouvent dans la région équatoriale des deux océans et dans la zone interessée par le courant circumpolaire antarctique. Chacune des régions possède ses caractéristiques propres en matière de variation saisonnière dans la production de thons et de marlins et de composition des prises par espèces.

(d) Il semble que l'introduction de la notion d'"écosystème" permette de mieux comprendre les caractéristiques des fonds de pêche. De plus, il est probable que le mécanisme du rassemblement des poissons à l'intérieur de chaque écosystème reflète nettement le comportement de chaque espèce.

LOS CALADEROS DEL INDO-PACIFICO PARA LA PESCA CON PALANGRES

(Informe provisional)

Extracto

Se dan detalles sobre los palangreros japoneses del Indo-Pacífico y sobre la productividad de los caladeros, según los datos más recientes.

(a) En 1960 fueron desembarcadas unas 360.000 toneladas en total, consistentes en tres partes de atún y una de otros pescados; esta última se componía de peces aguja y tiburones, en la proporción de un cincuenta por ciento de cada especie.

(b) El número de lances diarios, en toda la zona del Indo-Pacífico, se calcula en unos 360. Las operaciones más concentradas se practican en las zonas occidentales del norte del Pacífico y del Pacífico ecuatorial.

(c) Las zonas de elevada productividad como pesqueras de palangre se hallan en las regiones ecuatoriales de ambos océanos, en las de deriva del viento del oeste del hemisferio austral. Cada región presenta sus propias modalidades de cambio estacional en la productividad de atunes y peces aguja y en la composición de las capturas por especies.

(d) Para poder interpretar las características de las pesqueras, la introducción del concepto "ecosistema" parece ser eficaz. Además, es probable que el mecanismo de la agregación de peces dentro de cada ecosistema refleje marcadamente la forma de vida de cada especie.

1 INTRODUCTION

This report outlines the present activities of Japanese tuna longline vessels and the characteristics of the fishing grounds in the Indo-Pacific. This has already been described to some extent by the Nankai Regional Fisheries Research Laboratory (1953, 1959). However, the Japanese tuna longline fishery has developed conspicuously over the last few years, and both the areal expansion of the fishing grounds and the major catches by species have changed considerably.

2 CATCH BY SPECIES

Annual catches by Japanese tuna longline vessels fishing in the Indo-Pacific from 1958 to 1960 are shown in Table 1. The total landings of tunas and marlins were about 285, 000 tons in 1958 and increased steadily to about 360, 000 tons in 1960. Almost all the catches are fished by the Japan-based vessels, while 5 to 6 percent of the total landings are taken by the tuna mothership fleet and only 4 by the Samoa- and Santo-based longliners.

Fishes caught by the longline fishery consist of about three parts tunas and one part other fishes composed of one-half marlins and one-half sharks and miscellaneous fishes. Of tuna species, yellowfin are the most important, and bigeye are landed in almost equal quantity. In recent years, the landings of bluefin have increased rapidly, reflecting the exploitation of the southern bluefin fishing grounds in the southeastern parts of the Indian Ocean. Though albacore landings had been the largest before 1954, they have been declining markedly in importance in tuna fishery. Since the second world war, the tuna longline ground of Japanese vessels has expanded so remarkably that the landings of yellowfin, bigeye, and bluefin have greatly increased. On the other hand, it can be said that the exploitation of the albacore ground has scarcely started.

3 ACTIVITIES OF LONGLINE VESSELS

Fig. 1 shows the number of sets by day by area of tuna longlines for the period September 1957 to March 1961, on the basis of logbook data received from experimental and commercial longline vessels, and statistics on the number of days at sea of fishing boats by vessel size-class (Japan, 1959 - 1961). It may be assumed that the data used here cover all the research vessels and the boats belonging to the tuna mothership fleet, and from 50 to 60 percent of commercial vessels. Data on Samoa- and Santo-based longliners are not included in **Fig. 1.**

The number of sets per day through the entire Indo-Pacific is estimated to be approximately 360. About 70 percent of all fishing vessels concentrate in the western north Pacific and the western equatorial Pacific. The number of sets in the Indian Ocean, the western South Pacific (south of 10°S and west of 170°W), and the eastern equatorial Pacific (east of 170°W) accounts for almost 30 percent of the total, that is 100 to 110 per day - or respectively 40 to 50, 20 to 30, and 30 to 40 for the three areas.

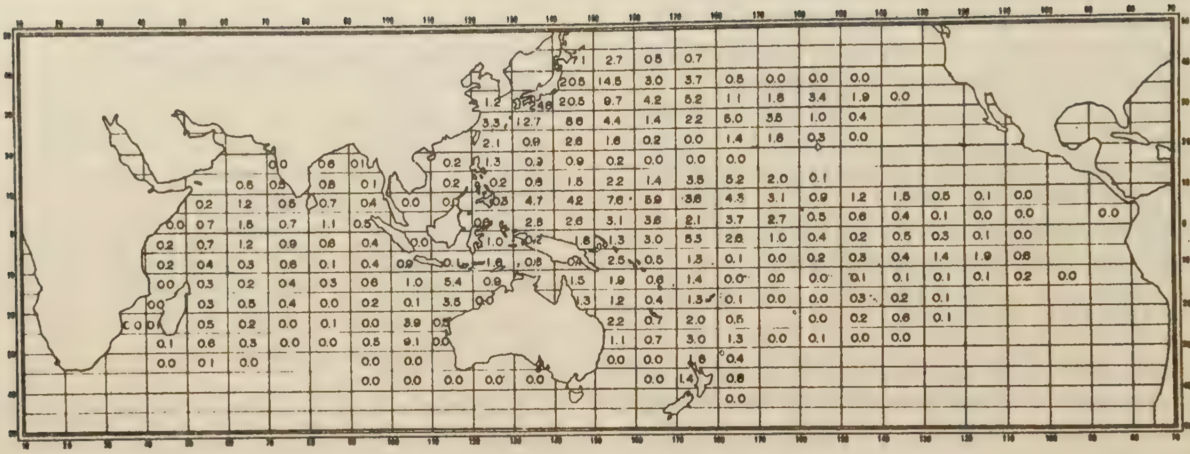
About half of the longline vessels operating in the Indian Ocean crowd into the relatively limited area off the coast of northwestern Australia and catch Indomaguro (southern bluefin?). In the western South Pacific, nearly half of longline boats belong to the tuna mothership fleet; and it is estimated that the Samoa- and Santo-based longliners work 20 sets a day, these activities being in addition to those shown in Fig. 1. In the eastern equatorial Pacific, the number of active longline vessels has gradually been increasing. Their main object is bigeye.

4 PRODUCTIVITY OF THE FISHING GROUND

Fig. 2 and Fig. 3 show the seasonal distribution, as summer and winter types, of mean catch weight of tunas and marlins per 1, 000 hooks. Roughly speaking, as a longline vessel generally uses 1, 500 to 2, 000 hooks to an operation, the catch amount in each operation may be considered to be nearly double that indicated in these figures.

It can be seen that, in the Indo-Pacific, the most productive areas of tunas and marlins are the equatorial region, the northern part of the westerly wind drift of the southern hemisphere, and some of the waters adjacent to the latter area. In the westerly wind drift of the northern hemisphere, relatively high productivity is recognizable but not so remarkable as in that of the southern hemisphere.

In the equatorial regions of the Pacific and Indian Oceans, catch per 1, 000 hooks is more than 1 ton per year. In the western part of the equatorial Indian Ocean and the eastern part of the equatorial Pacific, it often exceeds 3 tons. Fig. 4 shows that the main catches in the equatorial region are yellowfin and bigeye.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1.2 24.8 20.5 9.7 4.2 8.2 1.1 1.8 3.4 1.9 0.0
3.3 12.7 8.8 4.4 1.4 2.2 6.0 3.8 1.0 0.4
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0.0

Fig. 1 Number of sets by tuna longliners by day and by area (mean value of the period from September 1957 to March 1961)

Source: Data of the Japan-based vessels and the tuna mothership fleet, excluding Samoa- and Santo-based longliners.

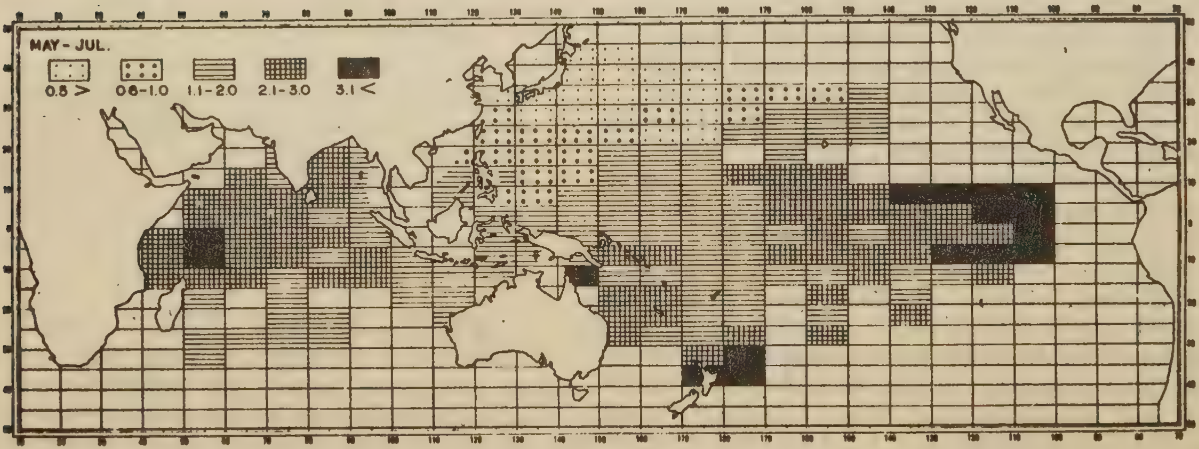
MAY - JUL.
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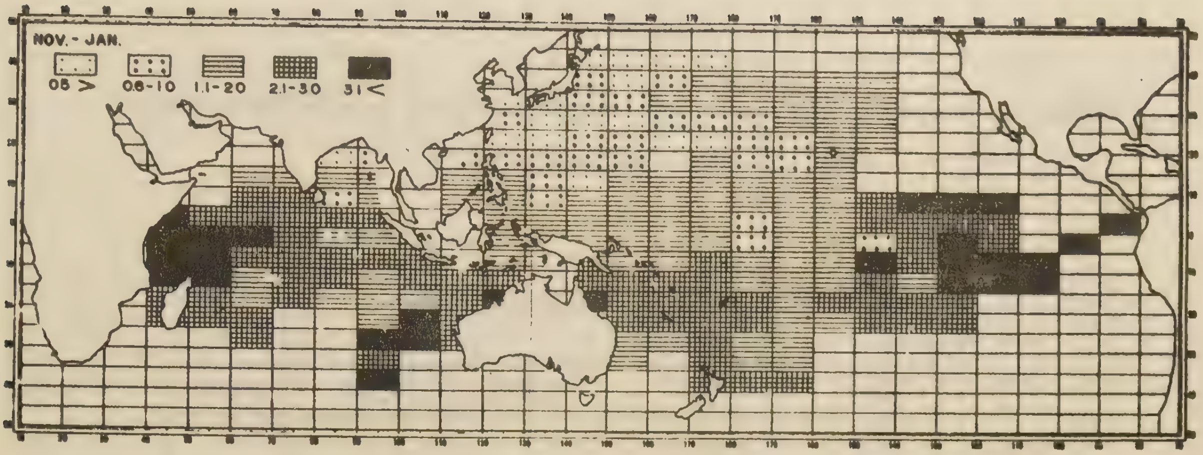
Fig. 2 Mean catch weight of tunas and marlins - northern summer type (May to July) (ton/1000 hooks)


NOV. - JAN.
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31<

Fig. 3 Mean catch weight of tunas and marlins - northern winter type (November to January) (ton/1000 hooks)

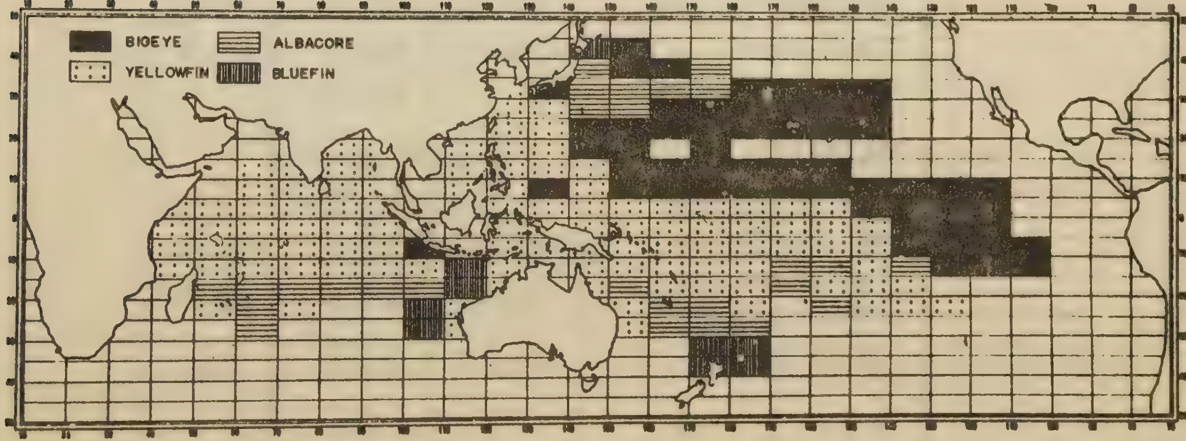
BIGEYE
ALBACORE
YELLOWFIN
BLUEFIN

Fig. 4 The dominant species of tuna, based on annual catch weight of each species

Table I

Catch in weight by the Japanese longline fishery from 1958 to 1960
(in 1000 tons)

A: Catch by the Japan-based vessels

Year	1958	1959	1960
Total catch	258.8	292.0	322.8
Tunas			
Bluefin	12.8	36.3	53.5
Albacore	24.0	32.6	35.5
Bigeye	65.7	68.8	65.4
Yellowfin	69.5	67.2	81.1
Sub-total	173.9	206.9	237.5
Marlins			
Striped marlin	8.4	8.7	7.4
Swordfish	12.8	13.1	13.9
(Black marlin (White marlin	27.0	24.3	22.0
Sub-total	50.1	48.7	45.5
Sharks	29.9	30.2	34.1
Other fishes	4.9	6.2	5.6

Table I (Cont'd)

B: Catch by the tuna mothership fleets

Year	1958	1959	1960
Total catch	14.4	20.7	24.0
Tunas			
Bluefin		6.6	0.6
Albacore	4.1	5.5	8.0
Bigeye	1.9	1.4	1.7
Yellowfin	4.7	2.9	8.6
Sub-total	10.7	16.5	18.9
Marlins			
Striped marlin	0.8	0.8	0.8
Swordfish	0.2	0.3	0.2
(Black marlin	1.0	0.8	1.5
(White marlin			
Sub-total	2.2	2.0	2.9
Sharks	1.2	1.8	1.8
Other fishes	0.2	0.3	0.4

C: Catch by the Samoa-and Santo-based longliners

Year	1958	1959	1960
Total	11.5	16.6	16.4
Tunas			
Albacore	8.2	12.0	11.9
Bigeye	0.4	0.7	0.9
Yellowfin	2.0	2.5	2.6
Sub-total	10.6	15.3	15.4
Marlins	0.9	1.2	1.0
(Sharks		0.1	0.1
(Other fishes			

Yellowfin are more dominant in the Indian Ocean, while bigeye predominate in the Pacific, especially in the eastern tropical area where they comprise approximately 70 percent of total tuna catch.

The fishing ground in the westerly wind drift of the southern hemisphere is that for southern bluefin. At present, the only areas exploited are in the waters north of New Zealand and off the coast of northwestern Australia, and yield as much as 2 tons per 1, 000 hooks. Information on these grounds is still insufficient.

In the sea area between the equatorial region and the westerly wind drift of the southern hemisphere and in the western North Pacific, albacore are the most dominant species. Productivity of tunas, however, is low in the region where albacore are dominant, often under 1 ton per 1, 000 hooks. This would indicate why the albacore ground has not been exploited to any large extent.

In the relatively high latitudes, especially in the westerly wind drift, productivity of tunas is distinctly changeable by season, and in most cases maximum yield becomes twice or more minimum yield. Consequently, the commercial fishery has been carried on in a limited period of the year. In the westerly wind drift of the Pacific Ocean, namely the waters to the poleward sides of the two subtropical convergences, productivity of tunas becomes high in the northern and southern winter seasons. Conversely, in the southern bluefin ground in the southeastern Indian Ocean, productivity increases in the southern summer.

Productivity is also subject to a seasonal change in the relatively low latitudes between the two subtropical convergences in the Pacific and north of the subtropical convergence in the Indian Ocean, although not to such an extent as in the westerly wind drift. As shown in Figs. 5 and 6, catch of tunas in these areas tends to increase in the Indian Ocean for the period November to January and in the Pacific from May to July. On the other hand, as shown in Figs. 7 and 8, marlins have a tendency to increase at the northern part of the above areas from May to July and at the southern part from November to January.

Each region has its own type of a seasonal change and, in consequence, of the most active fishing period. Therefore, if vessels of suitable size are chosen, they will be able to operate always in the highly productive region and to conduct a profitable fishery.

5 STRUCTURE OF THE FISHING GROUND (DISTRIBUTION PATTERN OF TUNAS)

The structure of the fishing ground is closely related to that of the ocean. Although it is thought that the swimming layer of yellowfin is far shallower than the equatorial water defined by Sverdrup et al.(1952), distribution of yellowfin, as shown in Fig. 9, corresponds well to that of the equatorial water in both oceans. A similar correspondence is observed between albacore and the central water (Fig.11). It is said that the resource water of southern bluefin might be the Subantarctic water (Robins, personal communication). In contrast to the above mentioned species, bigeye are distributed in various modes (see Figs. 4 and 10). In both the oceans, the immature group of bigeye occurs in the range of albacore, although somewhat less obviously in the Indian Ocean (Mimura 1962). The range of the mature group in the Indian Ocean corresponds to that of yellowfin, while in the Pacific it is contiguous to the northern side of the range of yellowfin and sometimes overlaps.

On the basis of the above-mentioned distribution patterns, it is supposed that the division of the environment corresponding to each water mass in the two oceans may be applicable to the corresponding surface waters in which tuna live. In addition, the dominant species is considered to vary with the division of the environment and is peculiar to each division irrespective of the quantity of all tunas therein. A division of the environment such as that described above may be taken to be suitable for that of a productive system or ecosystem as regards tuna. Furthermore, it seems that, in each ecosystem, the principle which decides the concentration of tuna is different from that which decides the dominant species and the species composition. The former would be associated fundamentally with the life forms of the constituents and the oceanographic conditions in each ecosystem, and the latter would reflect the structure of the biological community in each ecosystem. This problem has already been taken up and debated as the relationship between tuna and current system by Nakamura (1954), and Nakamura and Yamanaka (1959). However, such an assumption seems to be convenient for the environmental division of surface waters, but rather too restricted as the most basic division of ecosystems as regards tuna.

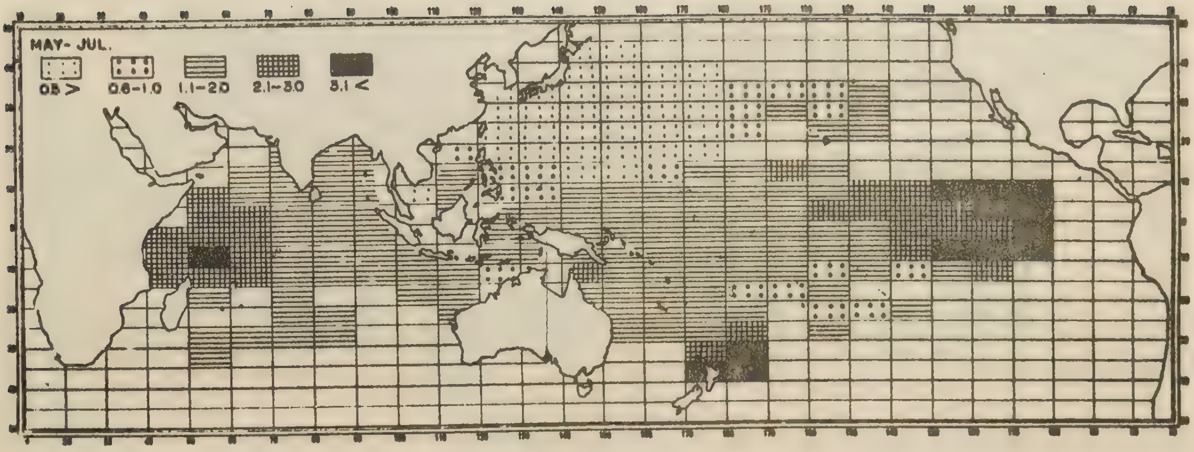
MAY- JUL.
0.5 >
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Fig. 5 Mean catch weight of tunas - nortnern summer type (May to July) (ton/1000 hooks)

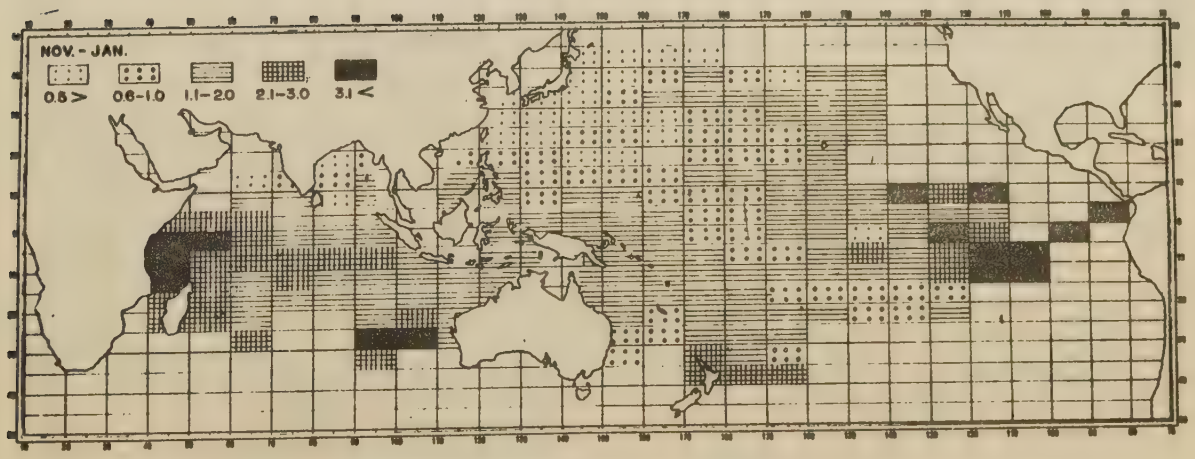
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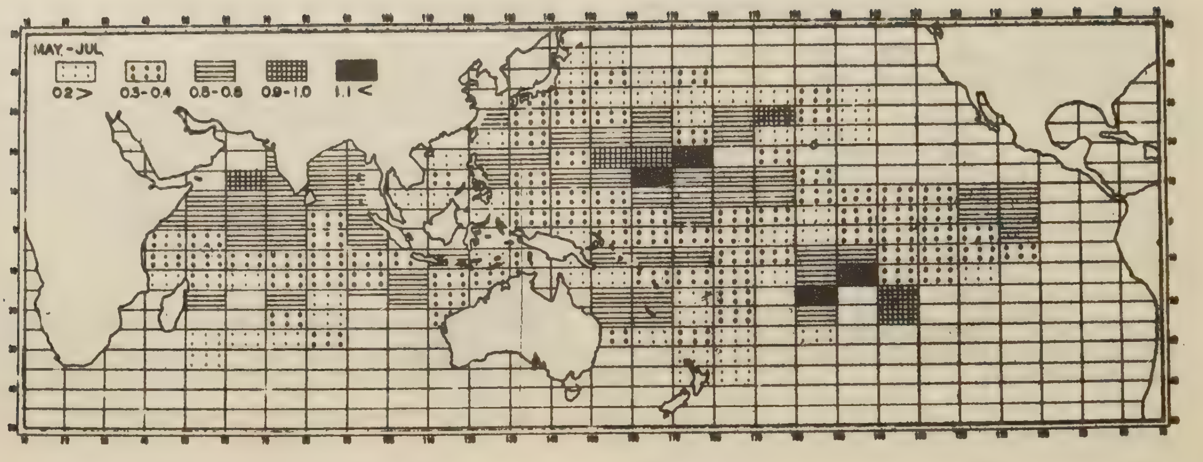
Fig. 6 Mean catch weight of tunas - northern winter type (November to January) (ton/1000 hooks)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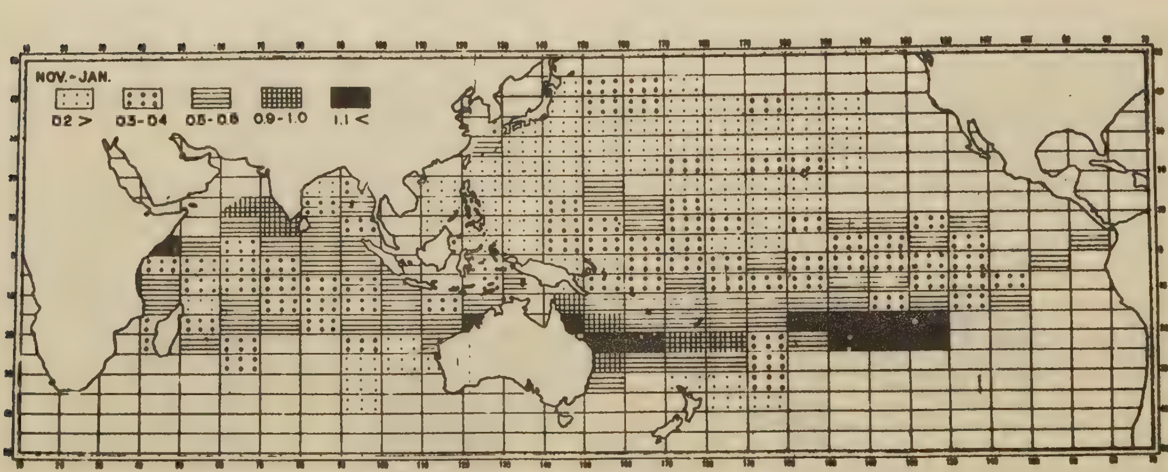
1.1 <

Fig. 7 Mean catch weight of marlins - northern summer type (May to July) (ton/1000 hooks)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0.3-0.4
0.5-0.8
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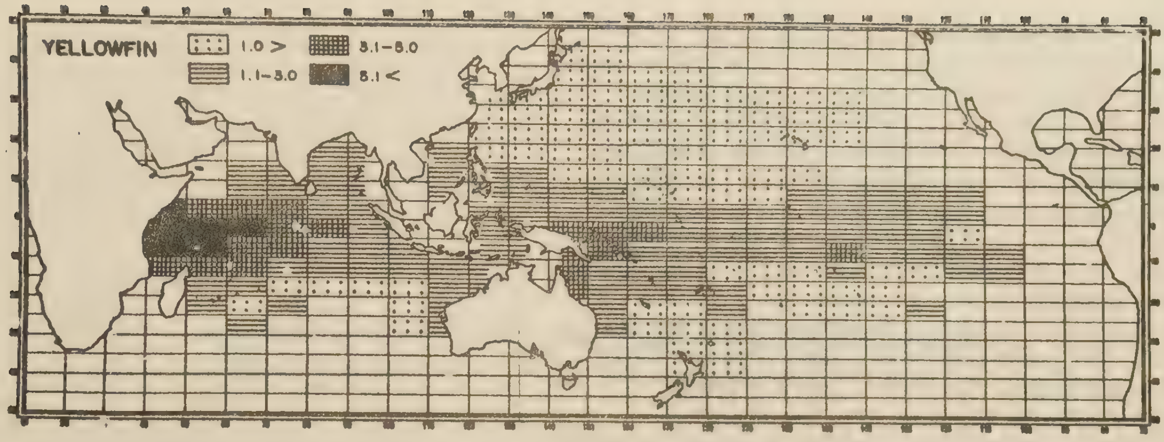
1.1 <

Fig. 8 Mean catch weight of marlins - northern winter type (November to January) (ton/1000 hooks)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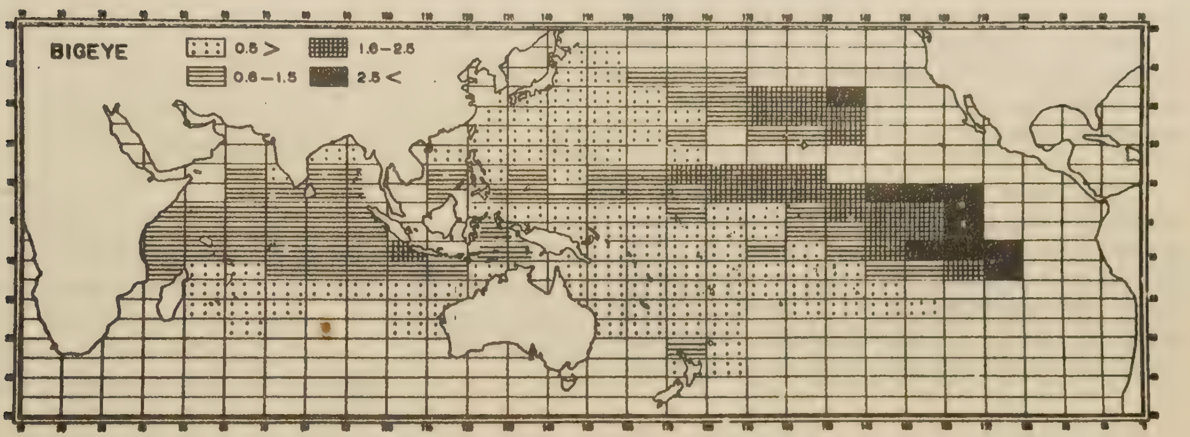
3.1-5.0
1.1-3.0
5.1 <

Fig. 9 Average yearly hooking-rate of yellowfin (catch/100 hooks)


BIGEYE
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1.6-2.5
0.6-1.5
2.5 <

Fig. 10 Average yearly hooking-rate of bigeye (catch/100 hooks)

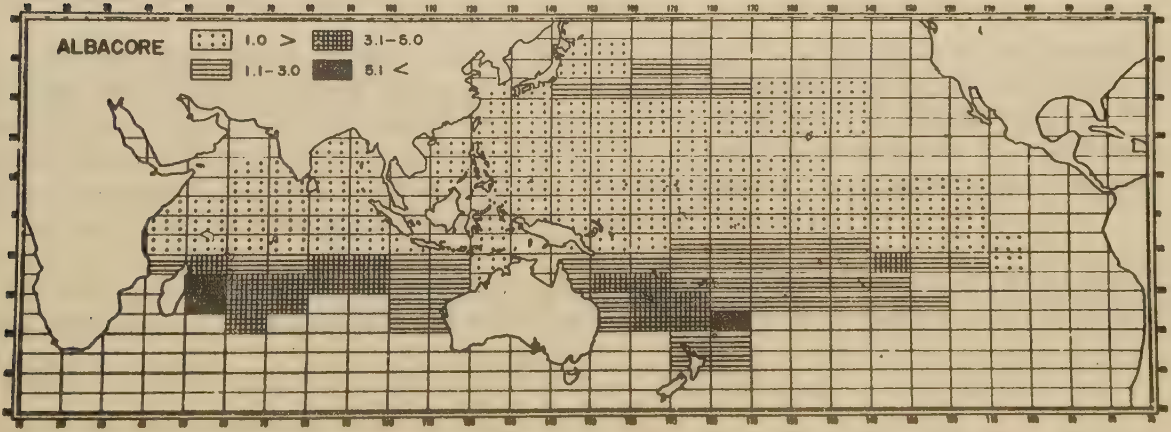
ALBACORE
1.0 >
3.1-5.0
1.1-3.0
5.1 <

Fig. 11 Average yearly hooking-rate of albacore (catch/100 hooks)

In each ecosystem, the density of tuna is not uniform. The area, where tuna are accumulated densley enoughto conduct an efficient fishery, belongs to a rather restricted part of each ecosystem. It seems difficult to explain universally the mechanism of the accumulation of tuna by a single principle. With regard to formation of the fishing grounds for yellowfin in the eastern equatorial Pacific, this has been explained fairly well in connection with the distribution of nutrient substances (Cromwell 1953; King and Hida 1957; Sette 1955). It has not been shown, however, that the same explanation is effective also for bigeye (Kamimura and Honma, 1962). It might be that the accumulation of bigeye is associated with the discontinuity of the oceanographic structure (Nankai Reg. Fish. Res. Lab., 1959). In the case of albacore in the North Pacific, which make an obvious seasonal migration - what causes the migration has not been established - it may well be that albacore are accumulated and fished near the turning point of the migration route.

It is likely that the conditions of formation of the fishing ground for tuna differ markedly by species. Within the same species, it is possible that also areal and ecological differences influence formation in varying degrees. Future research should be made, bearing in mind the results of previous investigations.

MONOFILAMENT GILL NET FISHING FOR SKIPJACK TUNA IN HAWAIIAN WATERS (A PROGRESS REPORT)

By

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Abstract

The Hawaiian skipjack fishery is showing signs of a decline. This is especially evident in the size of the fleet, which has decreased 40 percent since 1948. The problem is one of a static level of fishing efficiency of the pole-and-line method and increasing operational costs. The solution requires increasing the catch without a proportionate increase in cost.

The present study was carried out on a chartered skipjack boat from July 23 to September 29, 1961. The method of fishing was to locate a skipjack school, chum the school to the stern of the boat using live bait, set the net from a wooden bin while the boat moved ahead at chumming speed, carry out pole-and-line fishing, and haul in the net with a powerblock.

The method of net fishing which we have developed has not been tried elsewhere, therefore the field work was devoted to working out operational problems and evaluating different methods of fishing the gear. Although we were able to catch skipjack with the monofilament gill nets, the catches were not large enough to indicate that gill nets will replace the pole-and-line method. There were, however, indications that the nets can be used to effectively supplement the pole-and-line catches.

Recommendations are presented which should provide for a compatible combination of the two methods of fishing. We hope to resume field work during next year's skipjack fishing season.

UTILISATION DU FILET MAILLANT EN MONOFILAMENTS SYNTHETIQUES POUR LA PECHE DE LA BONITE A VENTRE RAYE DANS LES EAUX HAWAIENNES
(RAPPORT SUR L'ETAT DES TRAVAUX)

Résumé

La pêche à la bonite à ventre rayé est en régression à Hawai, comme le montre notamment l'importance de la flotte de pêche, qui a diminué de 40 pour cent depuis 1948. Ce déclin est dû au fait que le rendement de la méthode de pêche à la canne et à l'hameçon est demeuré stationnaire, tandis que les frais d'exploitation ont augmenté. Le problème consiste à augmenter les quantités pêchées sans entraîner un accroissement proportionnel des coûts.

La présente étude a été faite du 23 juillet au 29 septembre 1961 à bord d'un thonier loué pour la circonstance. La méthode adoptée consistait à repérer un banc de bonites à ventre rayé, à les attirer vers l'arrière du bateau en leur jetant de l'appât vivant, à mettre à l'eau le filet lové dans une cuve de bois tandis que le bateau avançait à l'allure d'appâtage, à pêcher à la canne et à l'hameçon, et à rentrer le filet avec un treuil à moteur.

La méthode de pêche au filet que nous avons mise au point n'ayant jamais été tentée ailleurs, le travail a consisté à résoudre les problèmes opérationnels et à comparer différentes techniques d'utilisation du filet. Bien que nous ayons réussi à capturer des bonites à ventre rayé avec les filets maillants en monofilaments synthétiques, les résultats n'ont pas été suffisants pour conclure que ces filets permettraient de constituer un appoint efficace à la pêche avec canne et hameçon.

Des recommandations sont formulées sur la façon de combiner les deux méthodes de pêche. Nous espérons reprendre les travaux pratiques au cours de la prochaine campagne de pêche à la bonite à ventre rayé.

PESCA DEL BARRILETE EN AGUAS HAWAIANAS CON TRASMALLO MONOFILAMENTO
(INFORME SOBRE LA MARCHA DE LOS TRABAJOS)

Extracto

La pesquería hawaiana del barrilete muestra síntomas de disminución, lo cual se evidencia singularmente en las proporciones de la flota, reducida al 40 por 100 después del 1948. El problema está en el nivel estático del rendimiento pesquero del curricán y el creciente costo de las operaciones. Su solución requiere un aumento en las capturas sin un incremento proporcional de costos.

El presente estudio fue efectuado a bordo de un atunero fletado especialmente para la pesca del barrilete, desde el 23 de julio hasta el 29 de septiembre de 1961. Consistía el método de pesca en localizar el cardumen; atraerlo hacia la popa de la embarcación con

cabo vivo; calar la red por su caja, avanzando el barco mientras seguía arrojándose cebo al mar; pescar con caña y sedal y cobrar la red con un cuadernal mecánico.

El método de pesca con red ideado por nosotros no ha sido ensayado en parte alguna; por consiguiente, nuestro trabajo experimental consistía en el planteamiento de problemas funcionales y en la evaluación de diferentes métodos de pesca con arte. Si bien pudimos capturar barriletes con trasmallo monofilamento, las capturas no fueron lo suficientemente abundantes para afirmar que estas redes pueden servir de eficaz complemento de la caña y sedal.

Se formulan recomendaciones que ofrecen una compatible combinación de ambos métodos de pesca. Esperamos poder reanudar el trabajo de campo durante la campaña de pesca del barrilete del año próximo.

1 INTRODUCTION

1.1 Present status of fishery[1]

In today's economy of many vigorously growing industries the Hawaiian skipjack fishery gives many indications of slowly deteriorating. From a modest start in the early 1900's this fishery has increased in importance and magnitude and in recent years the skipjack landings have represented from 50 to 70 percent of the total fish landings in the State of Hawaii (Yamashita, 1958). Since 1948 the annual skipjack landings have varied between 2,750 to 6,350 metric tons (Fig. 1). Total landings however, do not show the serious condition facing the fishery; instead, a survey of the size and age of the fishing fleet more accurately depicts the existing situation. The history of the fishery in the post second world war period shows an initial flurry of activity, born of optimism, which included the construction of nine new vessels between 1946 and 1950 (Fig. 2). This was followed by a stable period in the early 1950's when only one new vessel was added to the fleet. In recent years, with the withdrawal of a number of the older boats from the active fleet and the absence of new construction, the size of the fleet has been reduced from a total of 32 boats in 1948 (June 1951) to the present total of 20 boats. Even with the withdrawal of some of the older boats the present fleet may still be considered old; of the 20 boats fishing today, 7 were built between 1926 and 1931.

While the factors responsible for this state of decay in the fishery are complex, they are basically related to the wide fluctuations in the catch from year to year and to a method of fishing, with pole-and-line and live bait, which has remained virtually unchanged since the beginning of the fishery. This unchanging level of fishing efficiency, in combination with today's constantly rising operational costs, has had serious effects throughout the fishing industry, particularly during poor seasons. A similar situation which confronted the west coast tuna industry a few years back was resolved by increasing the fishing efficiency of the purse seiners by using nets of synthetic fiber and powerblocks to haul the nets (McNeely, 1961). Today the west coast fishery has regained its former stature of a thriving industry.

With regard to the efficiency of the pole-and-line fishery, there are several points on which this method can be considered inefficient. Studies by the U. S. Bureau of Commercial Fisheries Biological Laboratory in Honolulu show that approximately 50 percent of the fish schools actively pursued and chummed do not respond to the chum (Royce and Otsu, 1955; Yuen, 1959). Observations made on commercial boats also show that the catch per school is very small, suggesting that only a small fraction of each school is being landed. Yuen (1959) counted the catch from 73 schools successfully fished by commercial fishermen. The catch from 20 of the 73 schools (27 percent) was less than 25 fish per school and 53 (73 percent) of the schools gave catches numbering less than 125 fish per school (Fig. 3a). An additional factor contributing to the low catches is the relatively short time each school is fished. Of a total of 72 schools examined 60 (83 percent) were fished for a period of less than 25 minutes (Fig. 3b).

In essence, the solution to restoring the Hawaiian skipjack fishery into the family of growing industries is to increase the level of fishing efficiency, either by (1) improving the existing pole-and-line method or (2) introducing an entirely different mode of fishing. The present study is primarily concerned with the latter approach.

2 BACKGROUND MATERIAL

2.1 Plans

Prior to the field trials carried out from a chartered skipjack boat, a program was outlined which included: (1) an evaluation of the operational aspects of fishing monofilament gill nets, to be carried out on the Bureau's research vessel Charles H. Gilbert; and (2) a listing of possible methods of fishing the gear. The methods either fell into an active fishing category, in which a skipjack school is pursued and the net set in the midst of the school, or into a passive fishing category, where the net is set at a predetermined location and allowed to drift over a period of time, usually during the hours of darkness.

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[1] This study is being jointly financed by the State of Hawaii and the Bureau of Commercial Fisheries. Funds from the latter were made available by the Saltonstall-Kennedy Act.

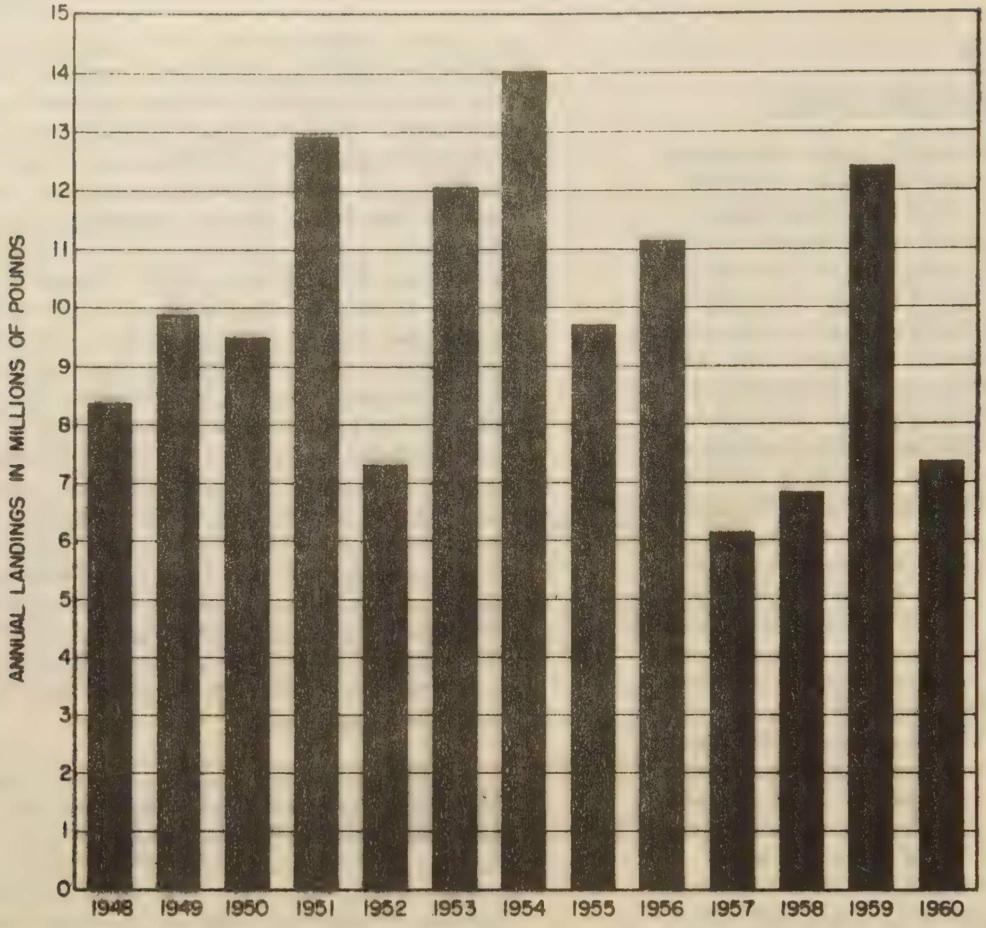


Fig. 1 Annual landings of Hawaiian skipjack fishery; 1948-1960

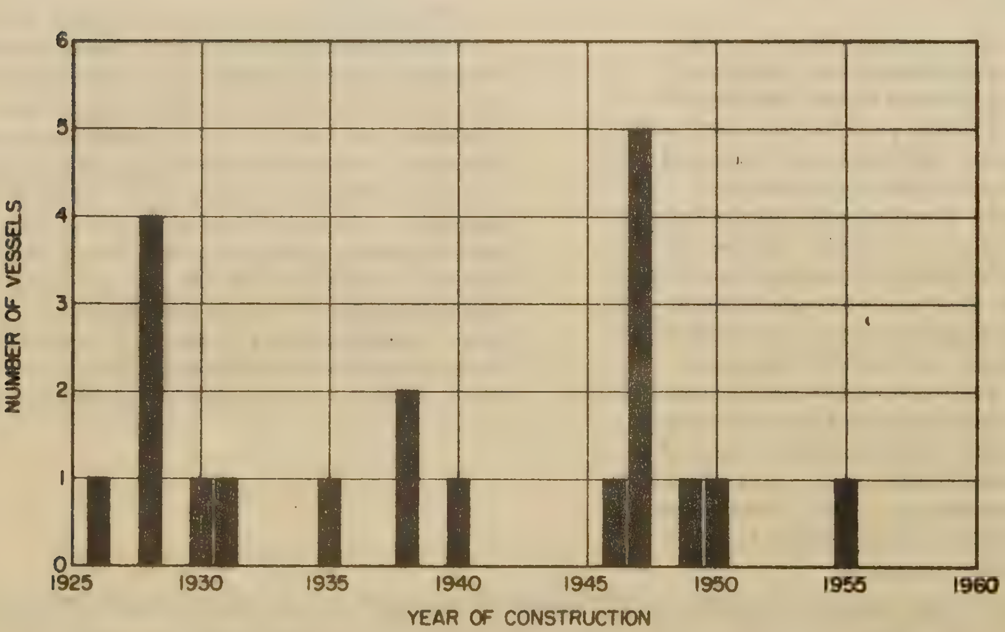


Fig. 2 Year of construction for skipjack boats active in 1961

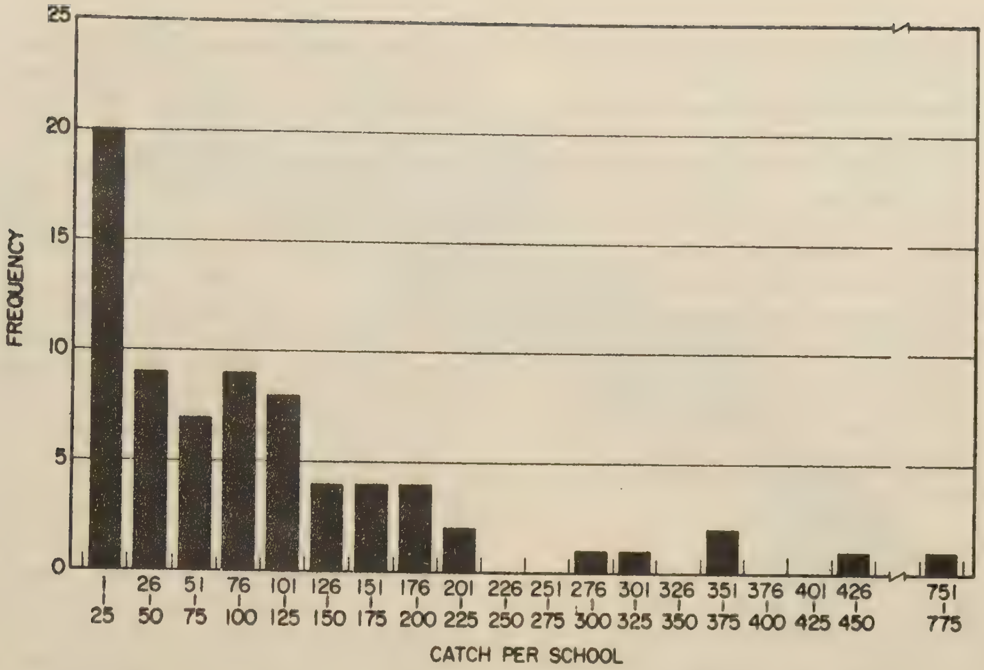


Fig. 3a Frequency distribution of skipjack catch per school (data from Yuen, 1959)

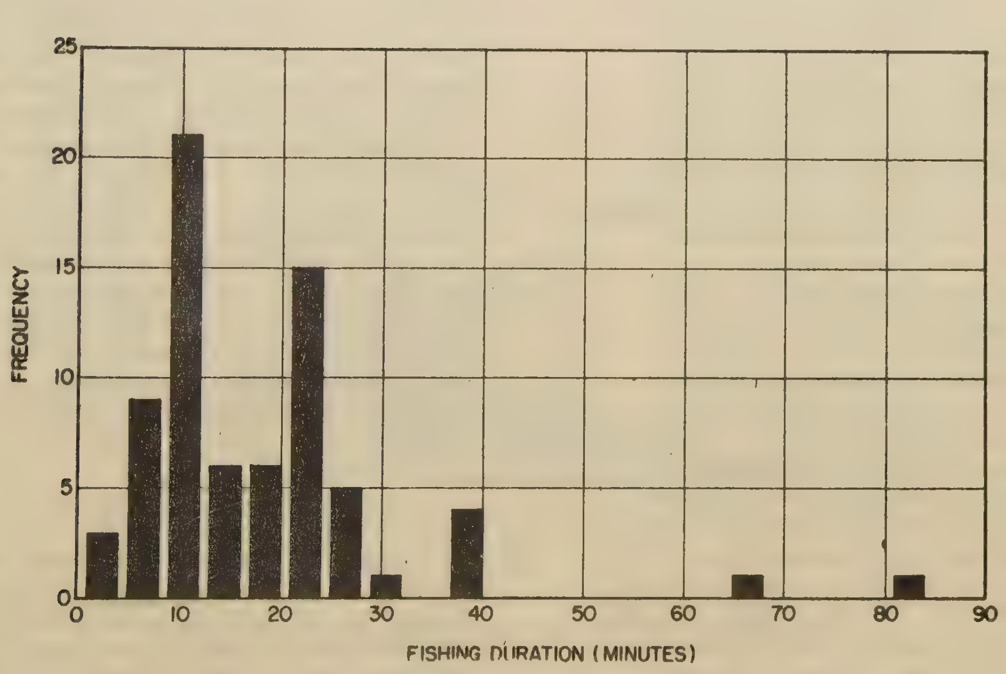


Fig. 3b Frequency distribution of fishing duration (data from Yuen, 1959)

Because of circumstances, including the availability of funds in late June and the receipt of gear in early July, the field program did not get underway until July 23, 1961. This late start was detrimental to the field program, since the skipjack fishery is seasonal with the peak catches made from June through August. In 1961 the effect of the delay was aggravated by the start of the fishing season a month earlier than usual. For these reasons, when field work was suspended on September 29, 1961, we were still in the early stages of evaluating modifications of the gear, and we were unable to do any work on the passive fishing phase of the program.

2.2 Monofilament nets

Before detailing the types and specifications of the monofilament gill nets purchased and used in the experiments, some information on the nature of monofilament is necessary to point out its advantages over other netting materials.

In recent years the use of monofilament fiber for gill nets has increased considerably throughout the world. Monofilament is one of several synthetic fibers commonly known under the general term "nylon." These fibers belong to the polyamide group, which along with other synthetic fibers have revolutionized the textile and fishing industries. Among the advantages nylon possesses over natural fibers are: (1) it is virtually unaffected by age, (2) it loses strength only on prolonged exposure to sunlight, (3) it is resistant to many chemicals, and (4) it is immune to bacteria, which permits leaving the gear in water for prolonged periods of time. The important attribute of monofilament nylon fiber is its very high transparency in water, which gives it a higher fishing efficiency than natural or other synthetic fibers. Molin (1959) discussed the results of comparative fishing tests using gill nets made of cotton, multifilament nylon, and monofilament nylon fibers. He reported that monofilament gill nets caught more than 7 times as many fish as cotton nets and approximately 4 times as many fish as multifilament nylon nets. The fishing efficiency of monofilament is so high that the states of Washington, Oregon and Alaska have banned these nets for salmon fishing.

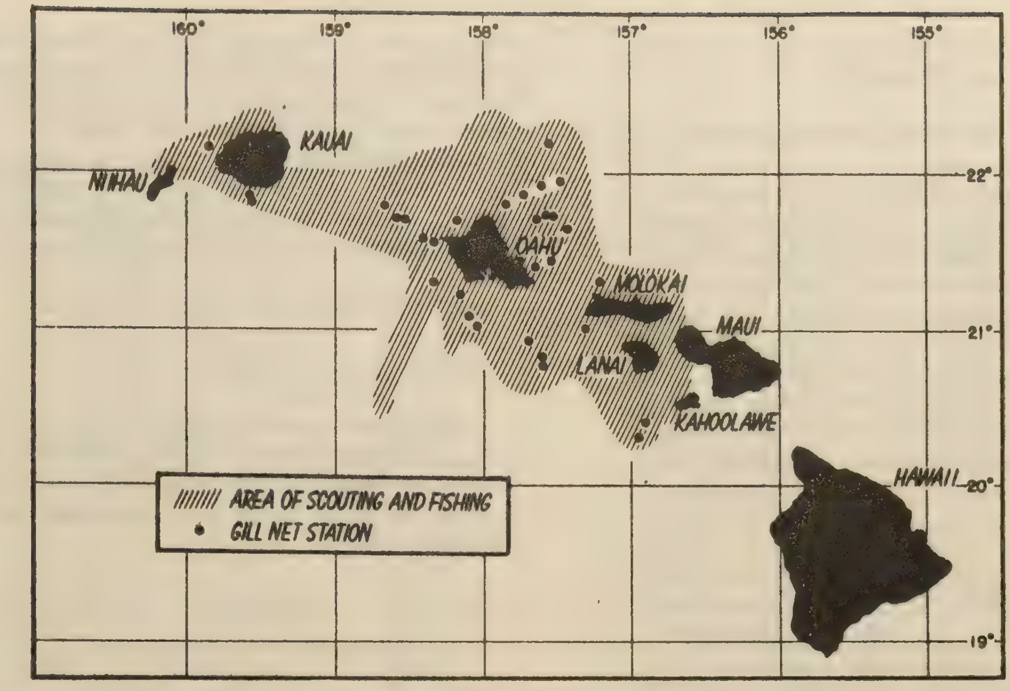
The monofilament gill nets used in the field trials in Hawaiian waters were of clear fiber of two mesh sizes. Based on simple tests consisting of passing skipjack of various sizes through mesh of different sizes, 5-1/2 in (13.97 cm) mesh (stretched measure) was selected for skipjack ranging from about 2 to 5 kilograms. The fiber for the 5-1/2 in mesh net was 22 MF (approximately 22-pound test line). Since the bulk of the season's catch is usually made up of fish ranging in size from 8 to 10 kilograms, monofilament nets made up of 7-3/4 in (19.68 cm) mesh (stretched measure) were chosen for catching these fish. The fiber for the 7-3/4 in mesh net was 35 MF (approximately 35-pound test line). Each unit of gear, called a shackle, measured 100 fathoms (hung measure) along the corkline and 102 fathoms (hung measure) along the leadline. The webbing was hung-in 50 percent along the corkline, i.e. 200 fathoms of webbing was hung on 100 fathoms of corkline. The 5-1/2 in and the 7-3/4 in nets both measured 10 fathoms in depth.

2.3 Vessel

Since the results of field trials must be applicable to the existing skipjack fleet, it was desirable to carry out the field work from a commercial skipjack boat. In this way the efficiency of the gear, the operational costs, and the earnings from the catch would be directly comparable with those of the commercial boats. For these reasons a commercial boat, M/V Broadbill was chartered. The Broadbill is typical of the sampan-type boats used exclusively in the Hawaiian skipjack fishery. She is 20.4 meters in length, has a sharp and high bow, and the pilot house is located just forward of midship (Fig. 5). The entire after section is open and low to allow for efficient pole fishing from the stern.

2.4 Results of preliminary trial

In May 1961, preliminary tests were carried out on the Charles H. Gilbert. Operational aspects of fishing the gear were examined and a simple comparative fishing test using only a single shackle of monofilament gill net was tried. The net was 100 fathoms long, 4 fathoms deep, and the mesh was 5-1/2 in (stretched measure). For comparison a 50-fathom length of multifilament nylon, dyed green was attached to each end of the monofilament shackle. The


160°
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NIIHAU
KAUAI
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MAUI
LANAI
KAHOOLAWE
HAWAII
/////// AREA OF SCOUTING AND FISHING
● GILL NET STATION

Fig. 4 Area of scouting and fishing, M/V Broadbill; July 23, 1961 - September 29, 1961

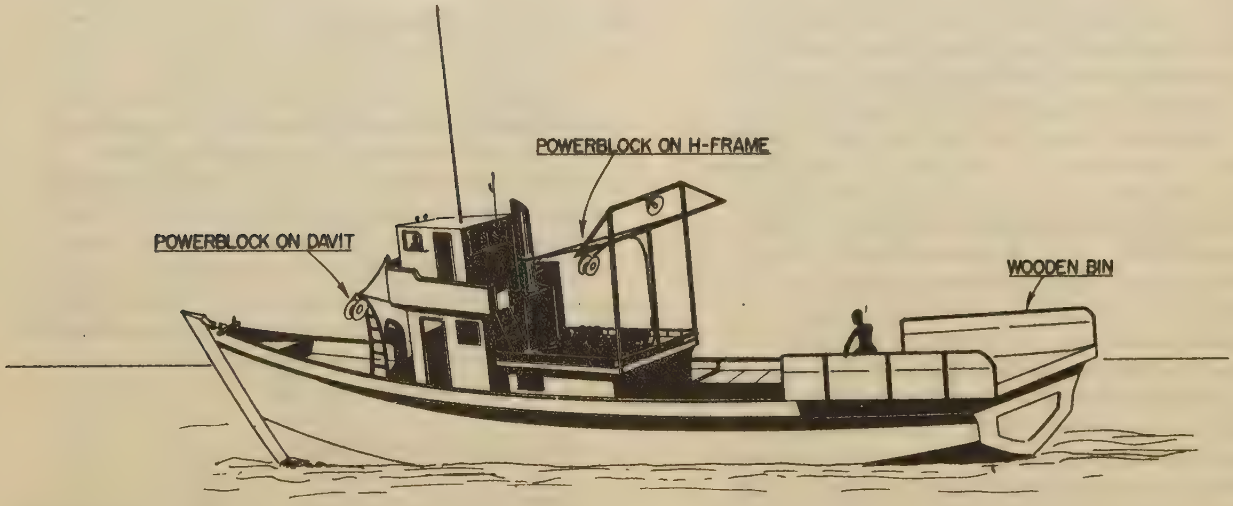
POWERBLOCK ON H-FRAME
POWERBLOCK ON DAVIT
WOODEN BIN

Fig. 5 Schematic diagram of M/V Broadbill

mesh size of the multifilament net was also 5-1/2 in (stretched measure).

The method of fishing developed in the preliminary trial, which appeared to be applicable on a skipjack boat, was to (1) locate a skipjack school by the usual method of looking for a "working" bird flock, (2) pursue and chum the school to the stern of the boat with live bait, and (3) pay-out the gill net from a wooden bin situated at the stern of the boat. During the setting operations chumming was continued, and upon completion of the set the vessel was maneuvered into a position with the bow at the net and chumming was then continued from the bow.

The results from three sets showed that skipjack can be taken by this method of active gill net fishing. The distribution of the catches also revealed the superiority of the monofilament netting over the multifilament nylon netting. Catches for the three sets were 34, 63, and 225 skipjack and only 5 of these were taken on the two multifilament nylon sections.

Direct observations of the net and the reaction of the skipjack to it were made through the underwater chambers of the Gilbert. The "hang" of the monofilament section in the water appeared ideal, with the meshes open and the leadline straight. The multifilament section, on the other hand, tended to bunch in, causing the meshes to close. In terms of visibility the difference between the two types of nets was striking, the monofilament net being far more transparent and difficult to see than the multifilament nylon. Observations on the reaction of the skipjack to the net were somewhat puzzling. At the multifilament sections the skipjack were apparently able to see the net at a considerable distance and avoided coming close to it. At the monofilament section the skipjack seemed to show a similar avoidance reaction at times. This, however, was not always the case as attested by the catch and also by some direct observations of fish being gilled. On a number of occasions skipjack were seen hitting the net at a relatively slow speed (unlike a feeding dash), suggesting that they did not see the webbing.

In order to evaluate the ability of skipjack to see monofilament line, five skipjack were caught by the pole-and-line method and transported alive to the ponds at Kewalo. These ponds were specifically constructed for tuna behavior studies (Nakamura, 1960). Although the test was limited in scope, it did show that skipjack are capable of seeing monofilament lines (22-pound test line was used) and avoiding them.

3 RESULTS OF 1961 FIELD TRIALS

3.1 General

Field work on board the M/V Broadbill commenced on July 23, 1961. Until operations were suspended on September 29, 1961, 45-1/2 days were spent in baiting, scouting, and fishing (Table I).

Table I

Distribution of effort:
July 23 to September 29, 1961

Days spent baiting	18
Days spent scouting and fishing	27-1/2
Days running without bait	1-1/2
Days spent repairing vessel and gear	10
Days of rest	12
TOTAL DAYS	69

The time schedule and the sequence of operations followed during the 2 months of field work were similar to those of the commercial skipjack boats. These involved locating and catching a supply of bait fish, taking on ice and other supplies, and then scouting and fishing the general areas where good commercial catches were being made. Fig. 4 shows the general area of scouting and fishing, while Table II lists the stations and type of activity undertaken.

3.2 Operational data

One of the major factors often overlooked when considering fishing in Hawaiian waters is the generally prevailing sea state and the closely related wind force. The Hawaiian Islands chain is located in the trade wind zone, and sea conditions usually range from "choppy" to "rough." Murphy and Niska (1953), in describing purse seining operations, considered the wind and sea conditions as principal factors limiting the use of this method of fishing in Hawaiian waters. Table III, taken

Table II

STATION LIST, M/V BROADBILL, JULY 23, 1961 TO SEPTEMBER 29, 1961

Station	Date	Position[1] Latitude	Position[1] Longitude	Type of Activity
1	7/23/61	Pearl Harbor		baiting - nehu[2]
2	7/24/61	21° 18.1' N.	158° 13.7' W.	chummed - abandoned - small skipjack
3	7/24/61	21° 15.2'	158° 10.2'	chummed - abandoned - no response - med. skipjack
4	7/24/61	21° 36.9'	158° 19.0'	chummed - abandoned - no response - sml. skipjack
5	7/25/61	*21° 34'	158° 19'	chummed - set 5-1/2" net
5A	7/25/61	21° 34'	158° 19'	chummed - abandoned - small yellowfin
6	7/25/61	21° 33.1'	158° 16.5'	abandoned - porpoise
7	7/25/61	21° 22.4'	158° 20.5'	chummed - abandoned - small skipjack
8	7/25/61	21° 09.4'	158° 01.5'	chummed - abandoned - small skipjack
9	7/26/61	Pearl Harbor		baiting - nehu
10	7/27/61	*21° 00'	157° 30'	chummed - abandoned - mahimahi[2]
11	7/27/61	*20° 45'	157° 05'	trolled around log
11A	7/27/61	3/4 mile south of Cape Kaea, Lanai		blind chumming - abandoned - no response
12	7/29/61	Kuliouou Stream		baiting - mosquito fish
13	7/31/61	Pearl Harbor		baiting - nehu
14	7/31/61	21° 13.5'	158° 02.5'	chummed - abandoned - no response
15	7/31/61	*21° 10'	158° 08'	chummed - abandoned - no response - med. skipjack
16	7/31/61	*21° 10'	158° 08'	chummed - abandoned - small skipjack
17	7/31/61	21° 05.7'	158° 11.1'	chummed - abandoned - small skipjack
18	7/31/61	21° 04.5'	158° 11.2'	chummed - set 7-3/4" net
19	7/31/61	21° 01.7'	158° 10.1'	chummed - set 5-1/2" net
20	8/1/61	20° 47.5'	158° 43.6'	chummed - abandoned - no response
21	8/1/61	21° 13.5'	158° 25.4'	chummed - abandoned - small skipjack
22	8/1/61	*21° 20'	158° 20'	chummed - set 5-1/2" net
23	8/2/61	*21° 23'	158° 12'	blind chumming - abandoned - no response
24	8/2/61	Off Barber's Point, Oahu		chummed - abandoned - no response
24A	8/2/61	Off Ewa Beach		blind chumming - abandoned - no response
25	8/3/61	Pearl Harbor		baiting - nehu
26	8/4/61	21° 02.0'	157° 20.2'	chummed - set 5-1/2" net
27	8/4/61	5-10 miles southwest of Lanai		trolled around log
27A	8/4/61	5-10 miles south of Lanai		chummed skipjack school - abandoned - no response
28	8/5/61	Kaiwi Channel		chummed - abandoned - no response
29	8/5/61	5-10 miles northeast Makapuu Pt., Oahu		chummed - set 5-1/2" net
30	8/9/61	Pearl Harbor		baiting - nehu
31	8/10/61	5-10 miles southeast Barber's Pt., Oahu		chummed - abandoned - no response
32	8/10/61	21° 05.9'	158° 25.1'	chummed - abandoned - yellowfin
33	8/10/61	21° 41.2'	158° 09.0'	chummed - set 5-1/2" net
34	8/11/61	5-10 miles north of Kahuku Pt., Oahu		chummed - abandoned - small skipjack
35	8/11/61	5-10 miles west of Kahuku Pt., Oahu		abandoned - school sounded
36	8/11/61	21° 35.9'	158° 21.2'	chummed - abandoned - small unidentified fish
37	8/11/61	21° 31.3'	158° 15.9'	chummed - set 7-3/4" net
38	8/11/61	21° 09.6'	158° 15.0'	chummed - abandoned - little tunny
39	8/11/61	21° 13.9'	158° 10.4'	chummed - set 5-1/2" net
40	8/13/61	Pearl Harbor		baiting - nehu
41	8/14/61	21° 38.4'	157° 29.1'	chummed - set 7-3/4" net
42	8/14/61	21° 44.5'	157° 30.9'	chummed - set 7-3/4" net
43	8/14/61	21° 33.6'	157° 23.8'	chummed - set 7-3/4" net
44	8/14/61	21° 33.2'	157° 28.8'	chummed - abandoned - skipjack school sounded
45	8/14/61	ca. 5 miles north of Makapuu Pt., Oahu		chummed - set 5-1/2" net
46	8/15/61	Pearl Harbor		baiting - nehu
47	8/16/61	Keehi Lagoon		baiting - iao[2]
48	8/16/61	Kaneohe Bay		night baiting - iao
49	8/17/61	Kaneohe Bay		baiting - iao
50	8/17/61	*21° 40'	157° 35'	chummed - abandoned - no response
51	8/17/61	*21° 17'	157° 12'	chummed - set 5-1/2" net
52	8/18/61	21° 13.7'	157° 24.0'	chummed - abandoned - small unidentified fish
53	8/18/61	21° 12.1'	157° 28.5'	chummed - abandoned - mahimahi
54	8/18/61	20° 49.5'	157° 37.8'	Porpoise
55	8/18/61	20° 52.6'	157° 39.0'	chummed - abandoned - small skipjack
56	8/18/61	20° 50.4'	157° 43.1'	chummed - abandoned - small skipjack
57	8/18/61	20° 55.8'	157° 46.7'	chummed - abandoned - small skipjack
58	8/29/61	Pearl Harbor		baiting - nehu
59	8/30/61	21° 32.8'	158° 21.1'	chummed - abandoned - small skipjack
60	8/30/61	21° 38.2'	158° 26.9'	chummed - abandoned - small skipjack sounded
61	8/30/61	*21° 40'	158° 28'	chummed - set 5-1/2" net
62	8/30/61	21° 43.5'	158° 31.9'	chummed - set 5-1/2" net
63	8/30/61	*21° 40'	158° 30'	chummed - set 5-1/2" net
64	8/30/61	21° 33.0'	158° 30.0'	chummed - abandoned - mahimahi
65	8/30/61	*21° 30'	158° 25'	chummed - abandoned - small unidentified fish
66	8/31/61	*21° 34'	158° 21'	chummed - set 5-1/2" net
67	8/31/61	21° 15.0'	158° 26.8'	chummed - abandoned - no response
68	9/1/61	Pearl Harbor		baiting - nehu
69	9/2/61	*21° 39'	158° 11'	abandoned - school sounded

[1] Positions preceded by * are based on dead reckoning.

[2] Nehu - _Stolephorus purpureus_; mahimahi - _Coryphaena hippurus_; iao - _Pranesus insularum_.

Table II

STATION LIST, M/V BROADBILL, JULY 23, 1961 TO SEPTEMBER 29, 1961 (con.)

Station	Date	Position 1/		Type of Activity
		Latitude	Longitude	
70	9/2/61	22° 02.7'	157° 53.6'	chummed - abandoned - no response
71	9/2/61	*22° 56'	157° 48'	chummed - abandoned - no response
72	9/2/61	*21° 49'	157° 42'	chummed - abandoned - school sounded (skipjack)
73	9/2/61	21° 44.0'	157° 38.5'	chummed - set 7-3/4" net
74	9/2/61	21° 43.9'	157° 46.1'	chummed - set 5-1/2" net
75	9/3/61	21° 40.0'	157° 34.2'	chummed - abandoned - no response (large skipjack)
76	9/3/61	*21° 40'	157° 30'	chummed - set 7-3/4" net
77	9/3/61	*21° 38'	157° 31'	chummed - abandoned - no response (large skipjack)
78	9/3/61	*21° 38'	157° 31'	chummed - abandoned - no response (large skipjack)
79	9/3/61	21° 39.1'	157° 32.1'	chummed - set 7-3/4" net
80	9/5/61	Pearl Harbor		baiting operation - nehu
81	9/6/61	21° 37.0'	157° 30.9'	chummed - abandoned - no response
82	9/6/61	21° 44.2'	157° 34.4'	chummed - abandoned - mahimahi
83	9/6/61	21° 44.2'	157° 34.4'	chummed- abandoned - no response
84	9/6/61	21° 46.0'	157° 34.5'	chummed - abandoned - mahimahi
85	9/6/61	21° 51.1'	157° 31.6'	chummed - abandoned - no response
86	9/7/61	20° 53.5'	157° 04.9'	blind chumming - abandoned - no response
87	9/7/61	*20° 48'	157° 02'	chummed - abandoned - small skipjack
87A	9/7/61	*20° 48'	157° 02'	chummed - abandoned - no response (mixed small & med. size skipjack)
88	9/7/61	20° 27.4'	156° 59.2'	chummed - set 5-1/2" net
89	9/7/61	20° 24.2'	157° 02.2'	chummed - set 5-1/2" net
89A	9/8/61	21° 06.6'	157° 40.9'	chummed - abandoned - no response
90	9/8/61	21° 01.7'	157° 51.1'	chummed - abandoned - mahimahi
91	9/8/61	20° 50.1'	157° 59.4'	chummed - abandoned - mahimahi
92	9/8/61	21° 11.1'	158° 07.9'	chummed - abandoned - mahimahi
93	9/8/61	Off Ewa Beach		blind chumming - abandoned - no response
94	9/8/61	Off Ewa Beach		chummed - abandoned - small skipjack
95	9/10/61	Pearl Harbor		baiting operation - nehu
96	9/11/61	21° 45.5'	157° 23.0'	chummed - set 7-3/4" net
97	9/11/61	21° 51.0'	157° 24.0'	chummed - abandoned - no response
98	9/11/61	21° 56.5'	157° 23.2'	chummed - set 7-3/4" net
99	9/11/61	21° 59.0'	157° 21.8'	chummed - abandoned - no response
100	9/11/61	22° 00.6'	157° 22.0'	chummed - abandoned - small skipjack
101	9/11/61	21° 59.1'	157° 22.9'	chummed - abandoned - small skipjack
102	9/12/61	Pearl Harbor		baiting operation - nehu
103	9/13/61	21° 36.5'	157° 28.1'	chummed - abandoned - no response
104	9/13/61	21° 28.9'	157° 25.8'	chummed - abandoned - no response
105	9/13/61	21° 53.6'	157° 42.2'	chummed - abandoned - small skipjack
106	9/13/61	21° 53.0'	157° 28.5'	abandoned - small skipjack
107	9/13/61	21° 54.0'	157° 27.0'	chummed - pole-and-line only - small skipjack
108	9/13/61	21° 46.3'	157° 30.8'	chummed - abandoned - no response
109	9/13/61	21° 48.5'	157° 29.5'	chummed - abandoned - no response
110	9/13/61	*21° 48'	157° 29'	chummed - abandoned - small skipjack
111	9/13/61	Off Mokumanu, Oahu		chummed - abandoned - no response
112	9/16/61	Pearl Harbor		baiting operation -
112A	9/17/61	*21° 50'	159° 35'	chummed - skipjack school sounded
113	9/17/61	*21° 50'	159° 35'	chummed - set 5-1/2" net
114	9/17/61	*21° 50'	159° 35'	chummed - set 5-1/2" net
115	9/18/61	Port Allan, Kauai		baiting operation - nehu
116	9/18/61	*22° 06'	159° 49'	chummed - set 5-1/2" net
117	9/18/61	Hanalei Bay, Kauai		baiting operation - nehu
118	9/19/61	*22° 07'	160° 07'	chummed - abandoned - no response
119	9/19/61	*22° 01'	160° 01'	chummed - abandoned - school sounded
120	9/19/61	*21° 54'	159° 42'	chummed - abandoned - small unidentified fish
121	9/20/61	Kauai Channel		no attempt - lack of bait
122	9/21/61	Pearl Harbor		baiting operation - nehu
123	9/22/61	Pearl Harbor		baiting operation - nehu
124	9/23/61	20° 56.5'	157° 46.5'	chummed - abandoned - no response
125	9/23/61	20° 56.5'	157° 46.5'	chummed - set 5-1/2" net
126	9/23/61	20° 52.3'	157° 45.4'	chummed - set 5-1/2" net
127	9/23/61	20° 53.2'	157° 45.3'	chummed - set 5-1/2" net, 7-3/4" net
128	9/26/61	Keehi Lagoon		baiting operation - nehu
129	9/27/61	21° 23.8'	158° 27.7'	chummed - abandoned - no response
130	9/27/61	*21° 31'	158° 17.5'	chummed - abandoned - small unidentified fish
131	9/28/61	21° 15.5'	157° 29.5'	abandoned - porpoise
132	9/28/61	20° 58'	157° 27'	chummed - abandoned - no response
133	9/28/61	20° 58'	157° 27'	chummed - abandoned - no response
134	9/28/61	20° 58.4'	157° 27.1'	chummed - abandoned - school sounded
135	9/28/61	20° 58'	157° 27'	chummed - abandoned - small skipjack

from the above paper, shows the average monthly wind force for several areas in the Pacific for 1951. The Hawaiian area shows a considerably higher proportion of force 4 (11 to 16 knots) or stronger winds than the other areas listed. The significance of these conditions is emphasized by the fact that the period of greatest trade wind predominance occurs during the summer, which is also the peak of the skipjack season.

Based on our limited experience, the gill net can easily and safely be fished in sea states up to wave heights of 2 to 3 meters and under wind forces estimated between 18 and 20 knots (Table IV). In rough seas the gill net acted as a sea anchor during hauling of the net.

The procedure of fishing the gill net from the Broadbill was the same as that developed in the preliminary trials on the Charles H. Gilbert. The nets were set from a 3 m x 3.7 m x 0.9 m wooden bin attached to the stern of the Broadbill (Fig. 5).

The net was allowed to pay-out freely while the vessel moved ahead at chumming speed (1-1/2 to 2 knots). The time required to set a 100-fathom shackle was approximately 2 minutes.

At the start of the field trials, the powerblock for hauling the net was situated on an H-frame which was located about amidships (Fig. 5). The net along with the catch was pulled over the powerblock and onto the deck. After hauling had been completed, the fish were removed from the net and the net was re-stacked in the bin. Although the hauling operation went very well in slight seas and winds, it became very difficult under strong trade wind conditions. This difficulty was traced to our inability to maneuver the vessel in proper relation to the lay of the net. To increase maneuverability the powerblock was relocated to a davit on the port side just forward of the wheelhouse (Figs. 5, 6a and 6b). This modification improved the hauling operation considerably. The hauling time (Table V) ranged from 7 to 45 minutes and averaged 14 minutes for 21 sets in which times were recorded. The catches on these sets ranged from 0 to 103 skipjack.

The most difficult aspect of gill net operation is the removal of fish from the net and the re-stacking of the net. In our experience, the time taken for the picking and re-stacking phases was much too long for purposes of commercial application (Fig. 7). It will be necessary to reduce the time by 50 percent or more in order to make the gill net method of fishing commercially feasible.

Before the field work ended the hauling technique was slightly modified in an attempt to reduce the total time required for the hauling--re-stacking phase. We noted that a large part of the catch became badly entangled after passing over the powerblock, primarily because it was necessary to bunch the 10

Table III

Percentage of force 4 or higher winds; (Murphy and Niska, 1953)[1/]

Month	Hawaiian Islands	Cape San Lucas, Baja California	Line Islands	Phoenix Islands
Jan.	63	-	16	46
Feb.	36	-	91	41
March	67	-	25	4
April	29	-	22	-
May	49	-	11	-
June	82	-	41	-
July	91	-	32	15
Aug.	89	-	-	32
Sept.	84	4	94	-
Oct.	46	2	22	10
Nov.	44	-	11	55
Dec.	76	-	50	17

[1/] Data from U. S. Pilot Chart for 1951.

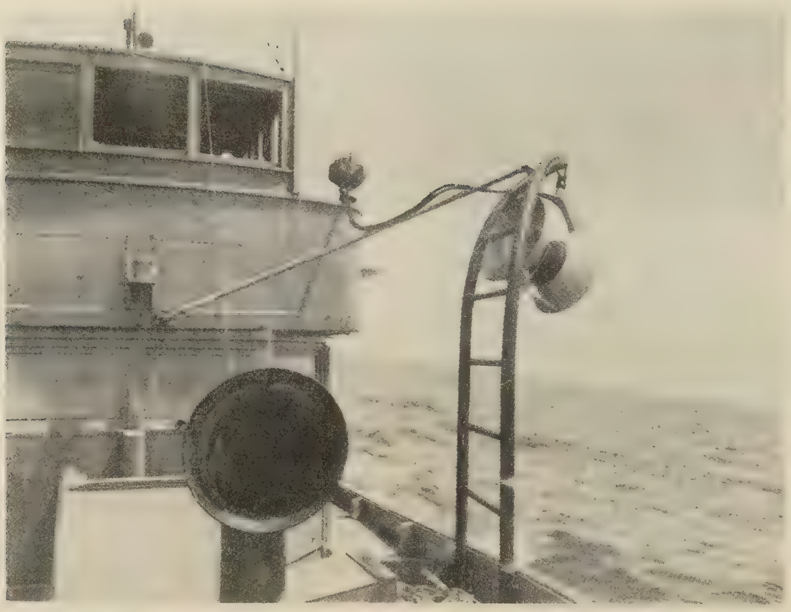

Fig. 6a Gill net powerblock secured to davit on port side of M/V Broadbill

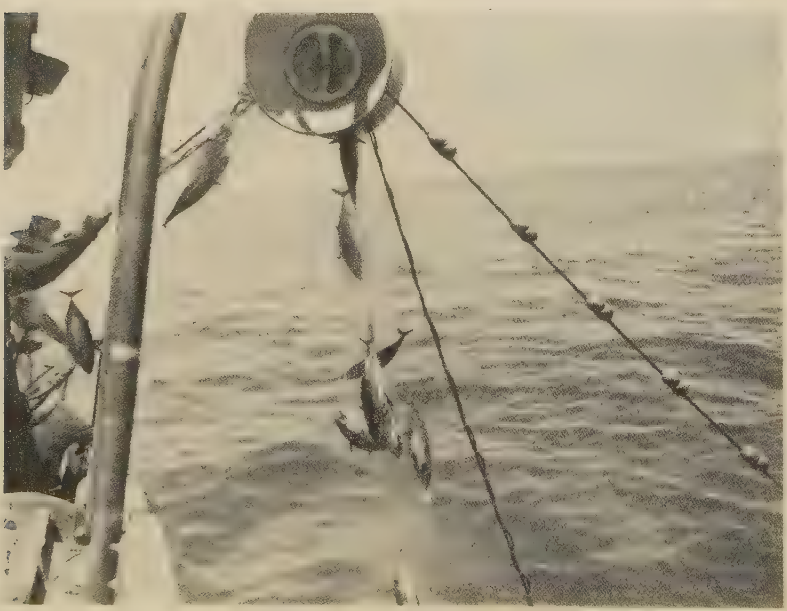

Fig. 6b Hauling-in of skipjack catch

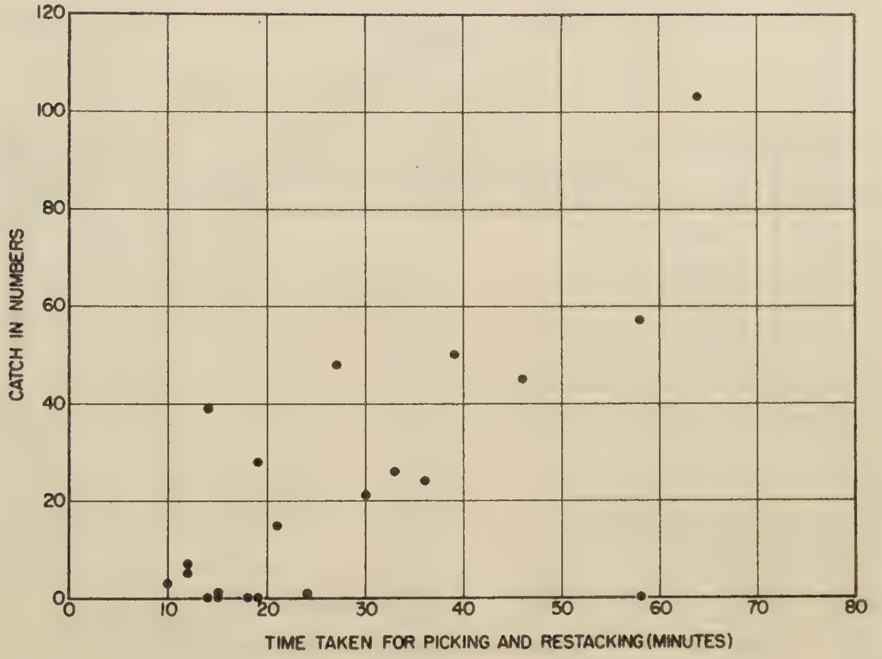

Fig. 7 Relation of total catch with time taken for picking and re-stacking

fathoms of webbing in the process. As a result of this bunching fish which were initially gilled in a single mesh inevitably became enmeshed in several others. The modification simply involved the removal of as many fish as possible before the net moved over the powerblock. Although an evaluation of this modification requires further trials, we feel that the increase in hauling time would be more than compensated for by the reduction in the time taken for picking and re-stacking. Moreover, the marketability of the fish should improve from the elimination of their contact with the powerblock. A further quality improvement should also result from the reduction in the time between capture and refrigeration of the fish.

Table IV

Summary of environmental conditions
on gill net stations

Station	Date	Wind		State of sea	Secchi disc reading
		Force	Direction		
5	7/25/61			1-3	
18	7/31/61	4-6	NE (?)	< 1	
19	7/31/61	4-6	NE (?)	< 1	
22	8/11/61	8-10	NE	1-3	35
26	8/4/61	10	NE	3-5	28
29	8/5/61	18-20	NE	5-8	
33	8/10/61	12-15	NE	3-5	
37	8/11/61	6-8	W	< 1	
39	8/11/61	12-15	ENE	3-5	
41	8/14/61	6	NE	3-5	31
42	8/14/61	12-15	NE	5	
43	8/14/61	12	NE	5-8	32
45	8/14/61	10-12	NE	3-5	
51	8/17/61	22	NE	5-8	
61	8/30/61	10-12	NE	1-3	
62	8/30/61	8-10	NE	1-3	
63	8/30/61	10-12	NE	1-3	
66	8/31/61	4-6		< 1	
73	9/2/61	15	NE	3-5	32
74	9/2/61	13	NE (?)	3-5	33
76	9/3/61				
79	9/3/61	11	NE	1-3	33
88	9/7/61	8	NE	< 1	42
89	9/7/61	7	NE	< 1	32
96	9/11/61	10	NE	3-5	33
98	9/11/61	7	NE	3-5	36
113	9/17/61	4-6	SE	< 1	
114	9/17/61	3	SE	< 1	36
116	9/18/61	8-10	SE		34
125	9/23/61	8-10	NE	1-3	
126	9/23/61	10-12	NE	3-5	
127	9/23/61	14-16	NE	3-5	

Table V

Summary of hauling nets, picking fish and re-stacking

Station	Mesh size of net 5-1/2 in.	Mesh size of net 7-3/4 in.	Time taken for hauling (minutes)	Time taken for picking and re-stacking (minutes)
22	x		11	14
26	x		13	19
33	x		45	30
37		x	18	18
39	x		13	46
41		x	17	15
43		x	9	15
45	x		12	36
51	x		11	58
62	x		10	10
63	x		11	27
66	x		11	12
73		x	9	24
79		x	11	14
89	x		15	64
98		x	12	12
113	x		7	19
114	x		14	39
116	x		11	33
125	x		11	21
126	x		13	50
		Average time	13.5	27.8

3.3 Baiting

Although field tests not involving the use of live bait were part of the overall plans, the results from the preliminary trials indicated that the best approach initially was to incorporate the use of live bait.

Bait fishing was carried out according to the method developed by the commercial pole-and-line fishermen. This involves scouting for schools of bait fish, usually the nehu (Stolephorus purpureus), in the bay areas. After a school is located a small-mesh bait net is set around the school from a skiff powered with an outboard motor. The net usually measures 80 to 100 fathoms long and is about 4 fathoms deep. After the set has been made, the ends of the net are taken in until only a small "pocket" remains. If the skipjack boat is near, the bait is transported in the "pocket" to the boat where it is brailed into the bait holds. If the distance between the locality of capture and the boat is great, the bait is first brailed from the "pocket" into the holding well on the skiff, transported to the boat, and again brailed, this time into the bait holds. June (1951) gives a detailed description of the entire operation.

While the supply of bait was adequate, we were hindered by a high bait fish mortality rate. Although accurate measures of the mortality rate could not be made, because the bait supply was continually being diminished by fishing, we estimated that it ranged from a low of 30 percent to a high of 70 percent. It was not determined whether this high mortality was the result of poor aeration in the bait wells, conditions inherent in the bait fish themselves, or handling during capture.

3.4 Gill net fishing

In undertaking this experimental fishing we realized that the results could range from a complete failure of the monofilament gill net to capture skipjack to a complete success in which the netting method would supplant the pole-and-line method of fishing. Based on the magnitude of our initial catches it seemed unlikely that the netting method would result in an unqualified success; instead there were indications that the gill net could conceivably supplement the pole-and-line catch. After an initial period of trial and error we therefore used a combination of the two methods in order to maximize the skipjack catch. The procedure was to locate a skipjack school by means of a "working" bird flock and, following the standard pole-and-line method, chum the school to the stern of the boat. Upon determination of the size of the fish, either by estimating the size from surfacing skipjack or by the capture of a few fish by pole-and-line, the proper mesh-size net was set. Chumming was carried out at a heavy rate during the setting operation, then reduced to the level generally used during pole-and-line fishing. Immediately after the set the fishermen moved back to the stern and commenced pole-and-line fishing. The pole fishing was continued until the school either sounded or the biting rate slowed down. Subsequently the pole catch was iced and the hauling of the gill net started.

During the 27-1/2 days of scouting and fishing, 116 fish schools were sighted and investigated (Table VI). Although a few schools were located by sighting skipjack breaking the surface, the majority were located by means of "working" bird flocks. Of the total schools sighted, 66 (57 percent) were identified as skipjack, however, gill net sets were made on only 32 of these. The skipjack schools not fished were either made up of fish too small for the gill net (18 schools) or were schools which could not be stopped by chumming (16 schools). The remaining 50 schools were either unidentified, because they did not respond to the chum (35 schools), or were composed of species other than skipjack (15 schools).

In order to evaluate the effectiveness of the gill net it was found necessary to try modifications of the gear. In the early stages of the field program we used the gear as purchased from the manufacturer without any changes. The catches from eight gill net sets made with the unmodified nets are given in Table VII. The catches were discouraging, but several areas for improving the fishing efficiency of the gear were observed. During the setting operation it appeared that the gill net was not sinking fast enough. To test the possible influence of the sinking rate of the net on the catch, we cut a 100-fathoms 5-1/2 in net into two sections. We doubled the leadline on one section and left the other with a single leadline. The procedure was to set the two sections successively on the same school. To eliminate a possible bias in the catch the setting order of the two sections was alternated. The results of this experiment are given in Table VIII. Except for one set there does not appear to be a striking difference between the catches made by the two nets. The exception was station 88, where 122 skipjack were taken on the double-leadline net and only 5 on the single-leadline net. The explanation for this is that the double-leadline section was set first, and although the chumming rate was kept constant throughout the setting operation, the school sounded during the setting of the single-leadline section.

On the preliminary trials in May we were fairly successful in increasing the catch by positioning the boat with the bow at the net and continuing chumming from the bow. After the first month of field work we noticed that on many occasions the school sounded when the boat was stopped at the net. To make it possible to keep the boat in motion during the continued chumming we removed a 20-by 25-foot section from the middle of both a 5-1/2 in mesh net and a 7-3/4 in mesh net. The idea was to set the net, keep the school at the stern by chumming, and cross over the net at this "gate". At the point of crossing we would increase the chumming rate to get the skipjack in a feeding frenzy near the net and possibly increase the catch. The results of fishing with this modification are given in Table IX. While a direct evaluation of the fishing efficiency cannot be made, the catches do not appear to differ significantly from those made with the unmodified nets. In defense of the low catches it should be pointed out that the 7-3/4 in net was set on three schools which consisted of fish too large for the mesh size (stations 76, 79 and 96). Skipjack in these schools ranged from 22 to 37 pounds, whereas we believe that the 7-3/4 in mesh net is most effective for skipjack less than 22 pounds in weight. Direct evidence that the gate modification was not successful was the

Table VI

Summary of scouting and gill net fishing

Date	Gill net set		Schools not fished				Total
	5-1/2 in	7-3/4 in	Skipjack No response	Small skipjack (< 3-4 lbs)	Unidentified No response	Other species	
7/24/61	-	-	2	1	-	-	3
25	1	-	1	1	-	yellowfin, porpoise	5
27	-	-	-	-	-	mahimahi	1
31	1	1	1	2	1	-	6
8/1/61	1	-	-	1	1	-	3
2	-	-	1	-	1	-	2
4	1	-	1	-	-	mahimahi	3
5	1	-	-	-	1	-	2
10	1	-	-	-	1	yellowfin	3
11	1	1	-	1	2	little tunny	6
14	1	3	1	-	-	-	5
17	1	-	-	-	1	-	2
18	-	-	-	3	1	mahimahi, porpoise	6
30	3	-	1	1	1	mahimahi	7
31	1	-	-	-	1	-	2
9/2/61	1	1	1	-	3	-	6
3	-	2	3	-	-	-	5
6	-	-	-	-	3	2 mahimahi	5
7	2	-	2	-	-	-	4
8	-	-	-	1	2	3 mahimahi	6
11	-	2	-	2	2	-	6
13	-	-	-	5	4	-	9
17	2	-	1	-	-	-	3
18	1	-	-	-	-	-	1
19	-	-	-	-	3	-	3
20	-	-	-	-	1	-	1
23	3	-	-	-	1	-	4
27	-	-	-	-	2	-	2
28	-	-	1	-	3	porpoise	5
TOTAL	22	10	16	18	35	15	116

Table VII

Results of fishing with the unmodified nets

SKIPJACK CATCH					
5-1/2 in Mesh Net					
Station	Date	Gill net[1]	Pole-and-line	Size range (pounds)	Comments
5	7/25/61	1	4	4-5	Poor set--net payed-out in bunch.
19	7/31/61	29	21	2-4	
22	8/1/61	39 (3)	53	3-4	
26	8/4/61	28	39	2-4	
29	8/5/61	37	86	3-6	Part of webbing (with undetermined number of gilled fish) cut off--net caught in propeller.
33	8/10/61	21 (2)	25	4-5	School sounded shortly after setting completed.
39	8/11/61	45	22	4-6	
45	8/14/61	24 (2)	4	2-6	
			7-3/4 in Mesh Net		
18	7/31/61	1	-	3	School sounded during setting operation.
37	8/11/61	-	5	12-20	School sounded at start of setting operation.
41	8/14/61	1	5	26-37	
42	8/14/61	-	3	26-37	
43	8/14/61	-	5	29-36	

[1] Numbers in ( ) represent fish lost at rail during hauling.

Table VIII

Relation between catching efficiency
and sinking rate

SKIPJACK CATCH[1]						
Station	Date	Double leadline	Single leadline	Pole-and-line	Size range (pounds)	Comments
61	8/30/61	-	Not set	6	4	School sounded after double leadline section set.
62	8/30/61	3	-	No pole fishing	4	
63	8/30/61	31	17 (2)	23	3-4	
66	8/31/61	1	6	7	3-6	
74	9/2/61	2 (1)	12 (1)	32	2-4	
88	9/7/61	117 (5)	5	2	2-5	School sounded during setting of the single leadline section.
89	9/7/61	49 (2)	54 (1)	446	3-6	

[1] Numbers in ( ) represent fish lost at rail during hauling.

Table IX

Results of fishing with a gate net

Station	Date	Skipjack catch[1]		Size range of skipjack (lb.)	Passage through gate		Comments
		Gill net	Pole-and-line		yes	no	
5-1/2 in. Mesh Net							
51	8/17/61	- (1)	13	3-8		x	Seas too rough for crossing over net.
113	9/17/61	-	10	-		x	School sounded during setting operation.
114	9/17/61	49 (2)[2]	2	3-5		x	School sounded after setting operation.
116	9/18/61	26 (1)	76	3-5	x		
125	9/23/61	15	7	3-6	x		
126	9/23/61	55 (4)[3]	138[4]	4-6	x		
127	9/23/61	27	59[5]	5-7		x	School sounded after setting operation.
7-3/4 in. Mesh Net							
73	9/2/61	1	4	14-16	x		
76	9/3/61	-	1	28		x	Unable to stop school; net set in front of school.
79	9/3/61	-	20	27-37	x		
96	9/11/61	1	74	22-32		x	Gate section tangled.
98	9/11/61	5 (2)	21	9-16	x		Net set too soon--school not at stern.

[1] Numbers in ( ) represent fish lost at rail during hauling.
[2] Additional catch: 1 mahimahi.
[3] Additional catch: 1 frigate mackerel; 1 small shark (species unknown).
[4] Additional catch: 1 frigate mackerel.
[5] Additional catch: 2 little tunny; 1 frigate mackerel.

reaction of three schools. On stations 116, 125 and 126 visual observations showed that the school was lost just as the boat passed through the gate. Prior to the time of crossing we were successfully fishing the school by pole-and-line, however, after we crossed the gate no skipjack were taken.

3.5 Cannery acceptability of gill net skipjack

In order to evaluate the acceptability of gill net-caught skipjack for canning three groups of fish were processed through the cannery. Each test included equal numbers of skipjack caught from the same school by the pole-and-line and gill net methods. Each fish was identified with a numbered metal tag and followed through the processing at the local cannery. The results of these three tests are given in Table X. In tests 1 and 3, definitely more blood spots occurred in the skipjack taken by the gill net method than those taken by the pole-and-line method. The results of test number 2, however, did not show such a difference.

The conflicting results obtained from the three tests point out the desirability of additional acceptability experiments. At this point it seems unlikely, based on the results of the second test, that the method of capture is solely responsible for the amount of blood spotting. In a number of the gill net-caught fish bruises were noted in the cooked flesh, possibly resulting from injuries sustained while going over the powerblock. A solution to this problem, discussed earlier, is to develop a means of extracting the fish before the net passes over the powerblock.

Table X

Cannery acceptability tests of gill net-caught skipjack

	Test No. 1		Test No. 2		Test No. 3	
Degree of blood spots	Pole-and-line	Gill net	Pole-and-line	Gill net	Pole-and-line	Gill net
None	1	-	1	1	3	1
Slight	24	16	20	18	4	3
More than usual (compared to commercial pole-and-line catch)	-	9	12	13	1	3
Rejected	-	-	-	-	2	3
TOTAL	25	25	33	32	10	10

4 DISCUSSION

From the results of the 2 months of field trials we have established that it is possible to capture skipjack with monofilament gill nets. We are, however, unable to judge the commercial applicability of this gear after such a short trial. In the 2 months we were only able to resolve some of the shortcomings in our methods of handling the gear, and we were still in the early stages of testing modifications of the gear.

Unless a modification of the gill net can be found which will increase the catching efficiency considerably above that so far experienced, the monofilament gill net will not supplant the pole-and-line method for catching commercial quantities of skipjack. There are indications, however, that the gear can be used effectively to supplement the catch made by the pole-and-line method. In the evaluation of the fishing efficiency of the pole fishery, evidence was presented that only a very small fraction of each skipjack school successfully fished was being landed. Since the number of schools successfully fished is also a low proportion of those fished (50 percent), any means of increasing the catch per school should be investigated. By incorporating a number of modifications in the gear and the operational method (see under Recommendations), we feel that the monofilament gill net can be used effectively to supplement the pole-and-line catch. We hope to test these modifications during the 1962 skipjack season.

5 RECOMMENDATIONS

The following are recommendations to be considered in the event this program is continued in 1962:

5.1 Bait fish

Use another kind of live bait, such as tilapia. Although the local anchovy (nehu) is a proven bait fish, the time taken to catch a load of bait fish and the high mortality rate of this species outweigh its proven quality of "raising" a school of skipjack to the stern of the boat.

5.2 Gill nets

Reduce the length of a shackle to 50 fathoms and the depth to 5 or 6 fathoms. The 100-fathom shackle is difficult to handle during the picking and re-stacking phase. Reducing the depth of the net will undoubtedly reduce the catch to some extent, but this would be compensated for by an appreciable reduction in the time taken for hauling, picking, and re-stacking. Under the present system too much time is spent in picking fish from the mass of webbing.

5.3 Setting modification

With a reduction in the size of the net the setting arrangement can be modified to increase fishing efficiency. Rather than set the nets from a large bin, which takes up the entire stern section, the setting can be done with the nets stacked in troughs placed on either side of the vessel. Each 50-fathom net would occupy a single trough with the corkline forward and the leadline at the stern. A simple double deck arrangement would make it possible to carry four nets. This arrangement would then leave the entire stern section free for pole-and-line fishing during and after the setting operation. Under optimum conditions, with a large school at the stern of the vessel, two nets could be set simultaneously.

5.4 Hauling modification

Place the powerblock in the bow section close to the midline of the vessel. Moving the powerblock inboard will permit picking the catch from the net before it moves over the block. This should reduce the total time taken for hauling, picking, and re-stacking, since the catch can be removed from the net most easily at this point. In addition, the hauling modification will mean fewer fish being lost at the rail and better quality fish.

Experience Paper No. 11

CLIMATIC PARAMETERS AND THE HAWAIIAN SKIPJACK FISHERY

By

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Abstract

Associations between the availability of skipjack to the Hawaiian fishery and their physical environment became apparent in a study of the oceanographic climate in terms of circulatory systems, associated water types, and the seasonal displacement of their boundaries. Good fishing success in Hawaii does not only depend on the right type of water (California Current Extension) bathing the islands but also on the right dynamic conditions as reflected by the shape of the heating curve and the time of initial heating (February) at Koko Head, Oahu. The index to be associated with skipjack availability was the heat advection, which contains time as a dimension. This led to the conclusion: If biological processes which contain time as a dimension are to be related to the environment, then, to be dimensionally correct, associated environmental parameters must also contain time as a dimension.

LES PARAMETRES CLIMATIQUES ET LES PECHERIES DE BONITES A VENTRE RAYE DES EAUX HAWAIIENNES

Résumé

L'étude du climat océanographique du point de vue des systèmes de circulation, des types d'eau associés et du déplacement saisonnier de leurs limites, a fait ressortir des rapports entre la disponibilité des bonites à ventre rayé dans les pêcheries hawaiiennes et les facteurs physiques du milieu. Le succès de la pêche dans les eaux hawaiiennes ne dépend pas seulement de la présence autour des îles du type d'eau approprié (prolongement du Courant de Californie), mais également des conditions dynamiques convenables, exprimées par le dessin de la courbe des variations thermiques et par l'époque où commence le réchauffement (février) à Koko Head (Oahu). L'indice devant être associé à la disponibilité des bonites à ventre rayé est l'advection thermique, qui renferme le facteur temps. D'où la conclusion suivante: si les processus biologiques, qui s'inscrivent dans le temps, doivent être rattachés à l'environnement, les paramètres écologiques connexes doivent aussi, pour être exacts, comporter le facteur temps.

LOS PARAMETROS CLIMATICOS Y LA PESQUERIA HAWAIANA DE BARRILETE

Extracto

Las conexiones entre la disponibilidad de barrilete o bonito de altura en la pesquería hawaiana y su medio ambiente físico se pusieron de manifiesto en un estudio del clima oceanográfico en función en función de los sistemas circulatorios, los distintos tipos de agua respectivos y el desplazamiento estacional de los límites de ellos. El éxito de la pesca en Hawai no solamente depende de la existencia del tipo apropiado de agua (Prolongación de la Corriente de California) que baña las islas, sino también de las apropiadas condiciones dinámicas reflejadas en la forma de la curva de variaciones térmicas y el tiempo del calentamiento inicial (febrero) en Koko Head, Oahu. El índice que hay que asociar con la disponibilidad de barrilete es el de la advección del calor, en el que se incluye el tiempo como una de las dimensiones. Esto llevó a la conclusión de que si los procesos biológicos que contienen el tiempo como una dimensión han de ser relacionados con el medio ambiente, entonces para que sean dimensionalmente correctos, los correspondientes parámetros ambientales deben también incluir el tiempo como una dimensión.

Traditionally, when marine biological distributions are considered in terms of their physical environment, they are related to properties such as the temperature, salinity, or nutrients which do not contain the dimension of time. In addition to these, however, there are parameters which express the time rate of change of properties, reflecting processes, and others which may express accelerations, reflecting forces in the environment. Such parameters contain the dimensions of T^{-1} or T^{-2} and may be important if such biological processes as reproduction, migration, and animal behavior are to be related to the physical environment. In recent years the discovery of associations between the availability of skipjack in the Hawaiian fishery and certain oceanographic parameters lends support to this view.

The Hawaiian skipjack fishery is located in an area where the annual range of surface temperature is approximately 3° C. and the annual range in surface salinity is approximately 0.6 ‰. Seasonal variations in the standing crop of zooplankton have not been clearly defined and seasonal variations in the concentration of nutrients such as phosphates, have not been demonstrated. These small changes are not believed to account for the seasonal and annual changes in the availability of skipjack as reflected in the landings of the fishery. The former range from 200,000 pounds per month in winter to more than 2,000,000 pounds per month in summer and the latter from 6,000,000 pounds per year as in 1957, to 14,000,000 pounds per year as in 1954.

Changes in the environment which may explain the changes in the fishery, however, become apparent when the oceanographic climate is studied in terms of circulatory systems, associated water types, and the seasonal displacement of their boundaries. Of importance in Hawaii are the North Pacific central and the North Pacific equatorial water types and the transition zone between these, the California Current Extension (Fig. 1). It was shown (Seckel, 1961) that the boundary between the California Current Extension with a salinity of less than 34.8 ‰ and the North Pacific central water with a salinity of more than 35 ‰ is well defined by a relatively sharp salinity gradient and generally lies just south of the islands during late autumn and early winter. During February or March it begins a northward movement passing through the islands during spring and reaching its northern position just north of the islands during July or August, when it begins its southward retreat. The movement of the boundary is reflected in changes of the surface salinity which are monitored by regular sampling near Koko Head, Oahu.

On the basis of heat budget considerations, four climatic periods which affect the Hawaiian waters were also deduced: (1) a warm advection[1] period during March and April, (2) a cold advection period peaking in July, (3) a second cold advection period peaking in October or November, and (4) a third cold advection period peaking during January or February. The warm advection period coincides with the initial northward movement of the salinity boundary. Under the influence of the spring and summer intensification of the trade wind system, the California Current Extension also intensifies and spreads, which is reflected by the summer cold advection period and the continued northward displacement of the salinity boundary. The autumn contraction and slackening of the California Current Extension results in the southward movement of the salinity boundary and the second cold advection period. The winter cold advection period is believed to be associated with an intensification of the circulation in the North Pacific central system.

Processes such as heat advection directly affect the rate of change of surface temperature, and when the latter is plotted versus time, a "characteristic heating curve" is obtained (Seckel, 1961). In the Hawaiian area the characteristic fluctuations primarily reflect changes in heat advection, so that they can be used to identify the advection periods described above. The characteristic heating curve for Koko Head, Oahu, based on 1951-1960 surface temperatures, is shown in Fig. 2. The fluctuations are characteristic for this location and may vary in magnitude or be displaced in time but can be identified in the heating curves of most of the years for this period. The spring warm and summer cold advection periods, which are of particular interest in this paper, are labeled in the figure. The time of initial warming, which coincides approximately with the beginning of the warm advection period and northward movement of the salinity boundary, is also indicated.

It is now possible to examine the Hawaiian skipjack fishery in terms of the climatic picture as reflected by these new indices. Some of the results to be presented were previously published

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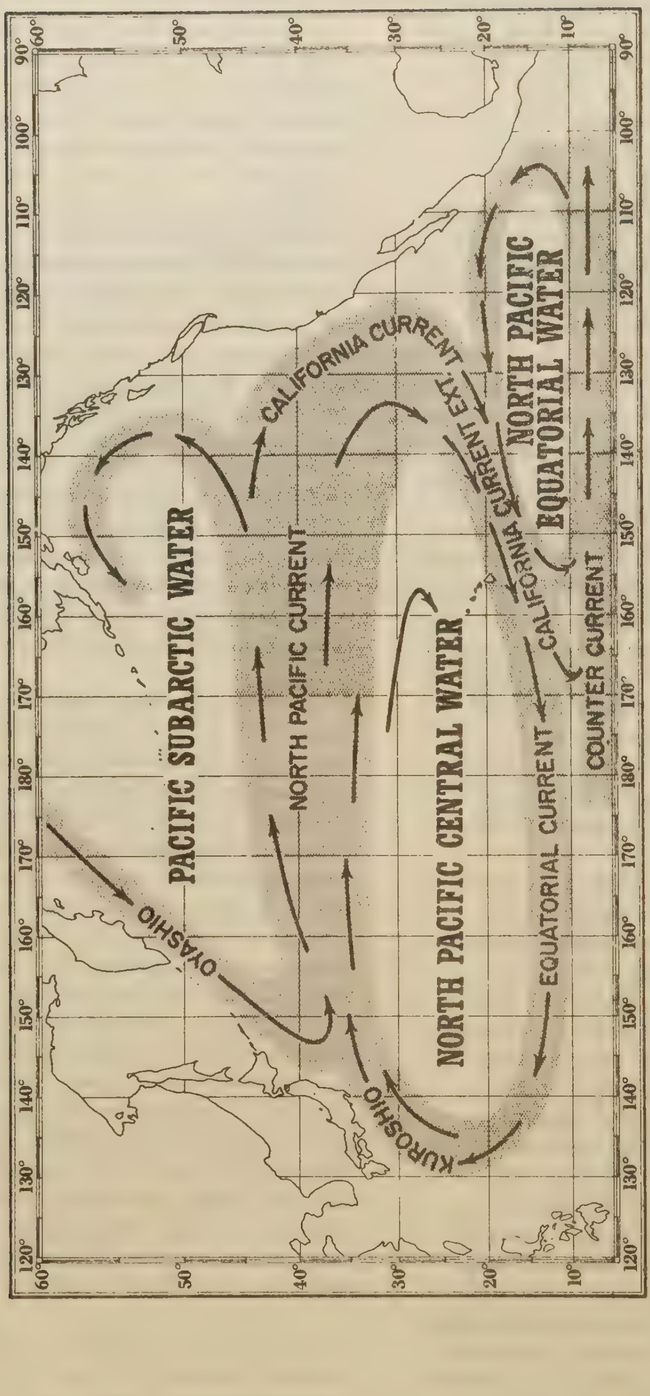
[1] Warm or cold advection means a change of temperature due to the movement of warmer or colder water into an area, respectively.


PACIFIC SUBARCTIC WATER
NORTH PACIFIC CURRENT
CALIFORNIA CURRENT
CALIFORNIA CURRENT EXT.
NORTH PACIFIC EQUATORIAL WATER
NORTH PACIFIC CENTRAL WATER
CALIFORNIA CURRENT
COUNTER CURRENT
EQUATORIAL CURRENT
OYASHIO
KUROSHIO
60°
50°
40°
30°
20°
10°
90°
100°
110°
120°
130°
140°
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170°
180°
170°
160°
150°
140°
130°
120°

Fig. 1 Schematic chart of the major North Pacific water types and currents

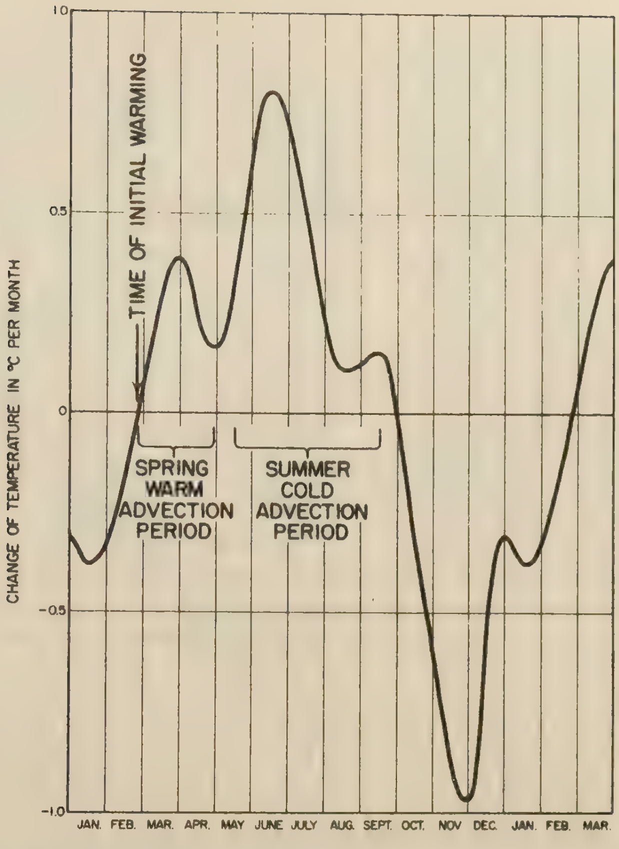

Fig. 2 Characteristic heating curve, Koko Head, Oahu

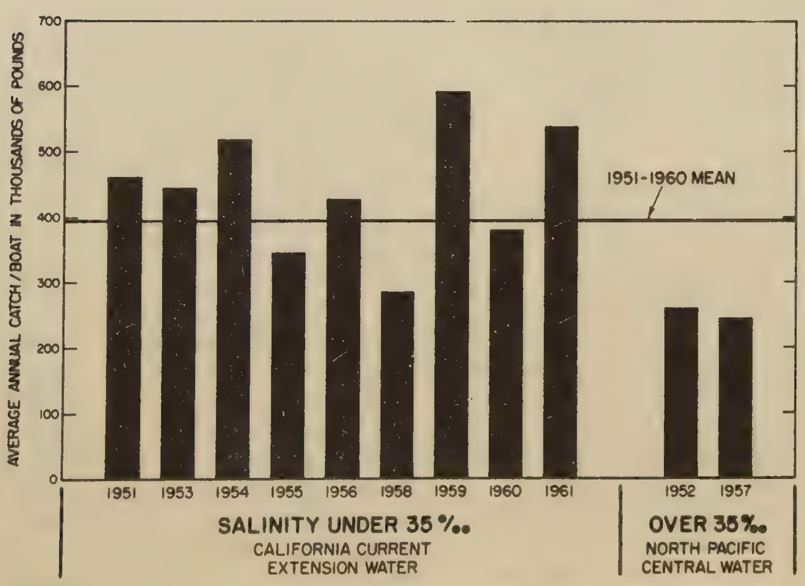

Fig. 3 Hawaiian skipjack landings, average annual catch per boat, as related to summer salinities

by Seckel and Waldron (1960). Considering summer salinities, it was found that during summers when the California Current Extension bathed the islands the annual skipjack landings were above average, whereas when the North Pacific central water bathed the islands during the summer, the annual landings were below average (Fig. 3). Three exceptions to this rule appear in the graph. The catch for 1958 is placed on the California Current Extension side of the graph because a salinity of 35 ‰ was chosen as an index of the salinity boundary. During that year, however, the minimum summer salinity was approximately 34.9 ‰, so that California Current Extension water did not bathe the islands and the association held true. The other exceptions, during 1955 and 1960, when landings were below average although California Current Extension water bathed the islands, indicate that other factors besides the type of water are of importance.

During the course of the climatic study it became apparent that the annual skipjack landings in Hawaii, reflecting availability, were also associated with the time of initial warming at Koko Head. Whenever this occurred in March, landings were below average, whereas when it occurred in February, landings were above average (Fig. 4). The time of initial warming is associated with the warm advection period and shows that dynamic conditions favorable to the fishery must be present well before the season begins. This association, therefore, provides the fishery with a predictive index which has so far been without exceptions.

Additional associations between the environment and the fishery become apparent when the 10-year Koko Head heating curve is examined together with the monthly skipjack landings (Fig. 5).

The shaded portions in each year indicate approximately the spring warm and summer cold advection periods, and the vertical bar, the time of initial warming. First, comparing the upper and lower panels, it is apparent that the peak catch period in each year coincides with the summer cold advection period. Then, the heating curves of 1954, 1959, and 1961 exhibit similarities: The time of initial warming occurred well before the end of February, and pronounced fluctuations, reflecting intensified dynamic processes, occurred between February and June. During these years landings were also well above average. There were, however, distinct differences in both the peak monthly landings per boat and the length of the peak fishing period.

Peak landings in terms of catch per boat per month were 142,000 pounds in 1954 and 119,000 pounds in 1959. The length of peak fishing as measured by the time between maximum rate of increase and decline in monthly landings was 2 and 3 months during these years, respectively. A reduction in peak catch rates in 1959 was therefore compensated by a longer fishing period. Looking into the length of the peak fishing period, one finds that these also correspond with differing lengths of the summer cold advection periods of 2.5 and 5 months during 1954 and 1959, respectively. As in 1954, the shorter fishing period of 2 months during 1961 also corresponded with a shorter cold advection period of 3.5 months.

Just as 1954 and 1959 exhibited similarities in the spring and summer portions of the heating curve, so the years following, 1955 and 1960, exhibited similarities: the initial heating began in March, the characteristic February to May fluctuations were absent, and heating peaked during April-May and then declined. The heating curves for these years are characteristic of the type to be found south of the islands (Seckel, 1961) and therefore reflect a northward displacement of the oceanographic climate. They also indicate that the effect of the intensified dynamic processes of 1954 and 1959 continued into the following year. This, then, indicates that 1955 and 1960, the exceptions in the relation between summer salinities and availability of skipjack, were years when the dynamics of the system was different from that usually found in the Hawaiian area.

This was also true for 1957, when initial warming occurred in March, the characteristic February to May fluctuations were absent, and peak heating in June was higher than average. In this case, the curve resembles one normally to be found north of the islands and therefore reflects a southward displacement of the oceanographic climate, as confirmed by high summer salinities. Therefore, during the poorest fishing year of the decade, neither the type of water nor the dynamic factors were those which are to be found during a good fishing year.

The Koko Head heating curve indices, the summer cold advection period, time of initial heating, pronounced spring fluctuations in the heating curve, the length of the summer advection period, and the heating curves characteristic of regions to the north or south of the islands (1957, 1955, 1960) reflect the dynamics of the environment.

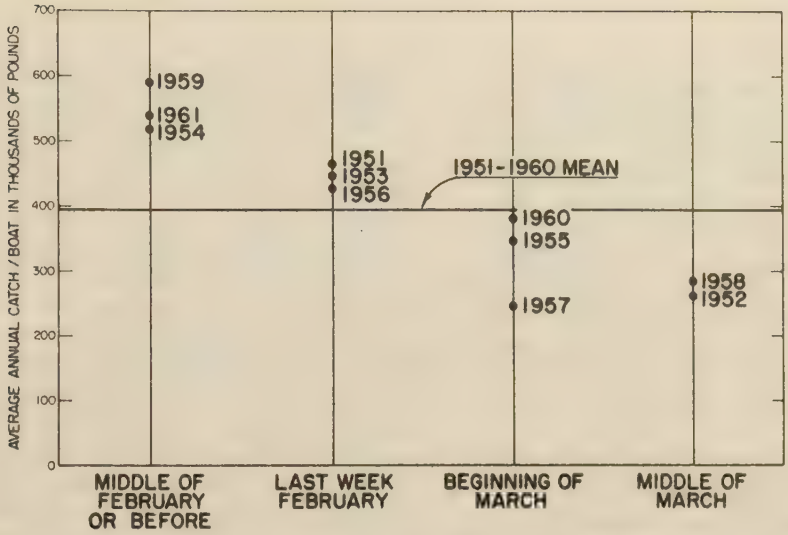

Fig. 4 Hawaiian skipjack landings, average annual catch per boat, as related to time of initial warming

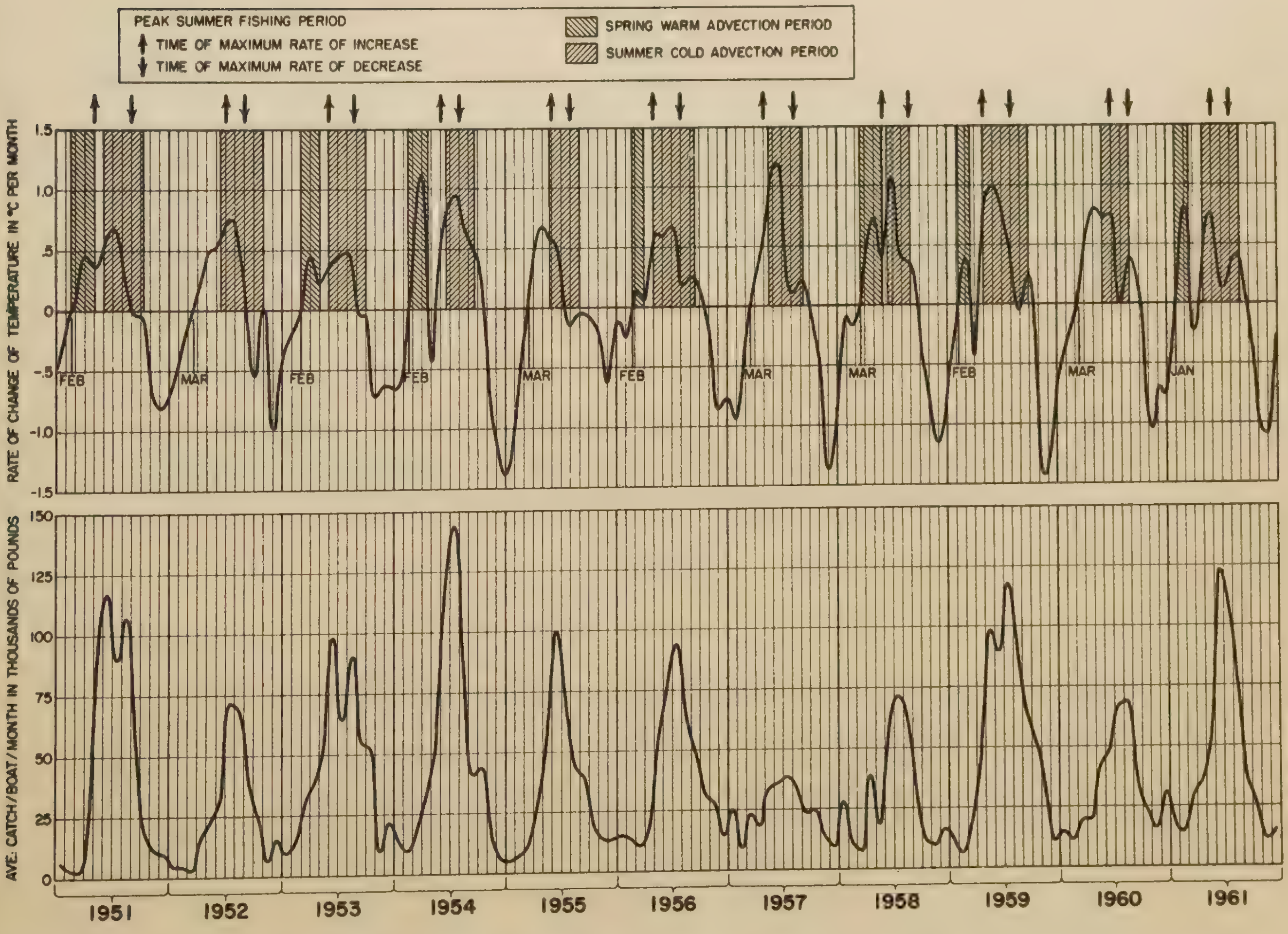

Fig. 5 Upper panel: Koko Head heating curve 1951-1961; lower panel: Hawaiian skipjack landings 1951-1961, in average catch per boat per month. (Heating curve Jan. 1951-Nov. 1955 obtained from surface water temperatures near Oahu)

It is evident, therefore, that in addition to a specific type of water, the summer skipjack population is also associated with a dynamic feature in the environment. The nature of the linkage between the fish and the environment, or even the nature of the dynamic feature, is not known at the present time. It is possible that they are produced by the barrier effect of the island chain in a varying current field and may involve the island wake and the boundary separating the North Pacific central from the California Current Extension water.

The index to be associated with the skipjack availability has been the heat advection, which contains the dimension T^{-1} and is directly reflected in the time rate of change of temperature, which also contains the dimension of T^{-1}. Indeed, the fluctuations in the heating curve reflect accelerations containing the dimension T^{-2} and therefore are in response to forces acting on the environment. This points to an important method of approach in ecological studies, when biological processes are to be related to the physical environment. The former imply time rates of change and accelerations, i.e., first and second time derivatives containing dimensions T^{-1} and T^{-2}, and therefore, to be dimensionally correct, associated environmental parameters must contain the same derivatives with respect to time. Thus, investigations of parameters containing the dimensions T^{-1} and T^{-2} may lead to new associations and to a better understanding of ecological problems and their solution.

Experience Paper No. 12

A METHOD FOR COMPUTING ESTIMATES AND VARIANCES OF RELATIVE LOG FISHING POWERS OF CALIFORNIA ALBACORE VESSELS

by

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Abstract

Log relative fishing powers of vessels in the California albacore fleet will be estimated from logbook data giving catch by boat, date, and area. The definition of log relative fishing power and the method of obtaining unbiased estimates follow Gulland (1956). A formula for the variance of estimated log relative fishing power is derived and an unbiased estimate of the variance is given.

METHODE DE CALCUL DE L'ESTIMATION ET DE LA VARIANCE DE LA PUISSANCE RELATIVE DE PECHE, EXPRIMEE EN LOGARITHMES, DES THONIERS CALIFORNIENS PECHANT L'ALBACORE

Résumé

L'estimation du logarithme de la puissance de pêche des bâtiments de la flottille californienne pratiquant la pêche de l'albacore repose sur les données fournies par le journal de pêche: prises par bateau, date et zone de pêche La définition de la puissance relative de pêche et la méthode employée pour obtenir des estimations non biaisées s'inspirent de Gulland (1956) Le document établit une formule donnant la variance de l'estimation de la puissance relative de pêche, et fournit une estimation non biaisée de la variance.

METODO PARA CALCULAR LAS ESTIMACIONES Y VARIANCIAS DE LA POTENCIA RELATIVA DE PESCA DE LOS BARCOS DESTINADOS A LA PESCA DE LA ALBACORA EN CALIFORNIA

Extracto

La potencia relativa de pesca de los barcos de la flota de la albacora en California se calculará con los datos del diario de pesca en donde figura la captura de cada barco, la fecha y la zona. Se definen la potencia relativa de pesca según el diario y el método para obtener estimaciones no viciadas, según Gulland (1956). Se extrae una fórmula para la variancia de la potencia relativa de pesca estimada, y se expone una estimación no viciada de la variancia.

1. INTRODUCTION

The California Department of Fish and Game collects catch and effort information from a large proportion of the California albacore fleet by means of voluntary logbooks. This information is tabulated to show number of fish by boat, date, and area (one-degree latitude by one-degree longitude) and is then used in catch-effort studies. Because fishing efficiency varies between vessels and may vary between time intervals for a given vessel, using statistics based on effort can result in false conclusions if the effort units are not adjusted to compensate for changes in fishing efficiencies.

If fishing efficiencies are related to physical characteristics of the vessels, effort can be adjusted by using some function of these characteristics. Also, it is quite possible that fishing efficiency is related to a vessel's captain and crew or to its gear in addition to, or instead of, the vessel itself. A discussion of the influence of these various factors will be found in FAO Fisheries Division Biology Branch, Parrish and Keir (1959). Whatever the case, a first step toward discovering such relationships is to estimate fishing efficiencies of a number of vessels.

The method of estimation is essentially that given by Gulland (1956) and is conceptually the same as that discussed by Beverton and Holt (1957). Notation and mathematical expressions differ somewhat from Gulland's in order to facilitate deriving the variance of the estimates.

2. ESTIMATING LOG RELATIVE FISHING POWER

Let B_k be a set of vessels fishing in a one-degree square area on a particular date, and let B_s be an arbitrarily selected B_k which will be referred to as the "standard set." We will consider the fishing efficiencies of the N vessels contained in the M sets B_k, where the B_k's are selected, such that each contains at least one vessel in common with the standard set. Symbolically, if i is a vessel and A is the set of vessels whose fishing efficiencies are under consideration,

$$i \in A \Longleftrightarrow \text{for some } k \ (i \in B_k \text{ and } B_k \cap B_s \neq \emptyset).$$

Figure 1 illustrates the relationship between the sets under consideration.

For the expected log catch of the i^{th} vessel fishing on the k^{th} date and area, we use the model of Gulland (1956),

$$E(C_{ik}) = \rho_i + \alpha_k + \beta_k,$$

where

C_{ik} logarithm of number of fish caught by the i^{th} vessel in B_k; $C_{ik} > -\infty$; $i = 1, \ldots, N$; $k = 1, \ldots, M$

ρ_i logarithm of fishing power of i^{th} vessel

α_k mean vulnerability of fish in k^{th} date-area

β_k mean density of fish in k^{th} date-area

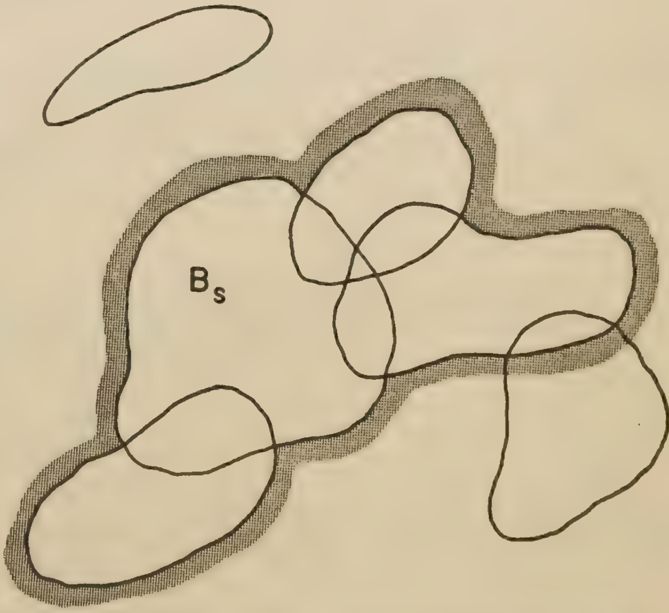

Figure 1. The set of vessels whose fishing efficiencies can be estimated, A, is within the shaded line. B_s is the standard set.

and E is, of course, the expected value operator. The fishing time associated with C_{ik} is taken to be one day. Also, we write Gulland's definition of the log fishing power of the q^{th} vessel relative to the vessels in B_s as

$$\rho_q - \frac{1}{n_s} \sum_{h=1}^{N} I_{B_s}(h)\rho_h, \tag{1}$$

with n_s the number of vessels in B_s, and the indicator function

$$I_{B_s}(h) = \begin{cases} 1 & h^{th} \text{ vessel in } B_s \\ 0 & \text{otherwise.} \end{cases}$$

Using indicators simplifies the notation involved in summing over sets and a further simplification will be accomplished by letting $I_k(i)$ mean $I_{B_k}(i)$. The identity $I_k(i)I_\ell(i) = I_{B_k \cap B_\ell}(i)$ is frequently employed in what follows, with $I_{B_k \cap B_\ell}$ being the indicator of vessels in both B_k and B_ℓ. It should be noted that $I_k(i)$ is not being considered an indicator function of a random event.

Henceforth, (1) will be used as a measure of the i^{th} vessel's fishing efficiency during a given season and it will be assumed that (1) is constant throughout the season.

An unbiased estimator of (1) is

$$Z_{q \cdot s} = \frac{1}{m_q} \sum_{k=1}^{M} I_k(q) Z_{qks} \tag{2}$$

where

$$Z_{qks} = \frac{1}{a_{ks}} \sum_{i=1}^{N} I_s(i) I_k(i)(Z_{is} - Z_{ik}) + Z_{qk}, \tag{3}$$

$$Z_{ik} = \frac{1}{n_k} \sum_{h=1}^{N} I_k(h)(C_{ik} - C_{hk}) \tag{4}$$

$$m_q = \sum_{k=1}^{M} I_k(q),$$

and

$$a_{ks} = \sum_{i=1}^{N} I_s(i) I_k(i).$$

To show $Z_{q\cdot s}$ is unbiased, we use

$$E(Z_{qks}) = \frac{1}{a_{ks}} \sum_{i=1}^{N} I_s(i)I_k(i) \left[E(Z_{is}) - E(Z_{ik})\right] + E(Z_{qk}) \tag{5}$$

and Gulland's (1956) result,

$$E(Z_{ik}) = \rho_i - \frac{1}{n_k} \sum_{h=1}^{N} I_k(h)\rho_h. \tag{6}$$

Then, from (5), (6), and (2),

$$E(Z_{q\cdot s}) = \rho_q - \frac{1}{n_s} \sum_{h=1}^{N} I_s(h)\rho_h \tag{7}$$

and the unbiasedness of $Z_{q\cdot s}$ as an estimator for the log fishing power of the i^{th} vessel relative to the vessels in the "standard set" is verified.

3. VARIANCE OF THE ESTIMATES

To determine the precision of $Z_{q\cdot s}$ and also to provide weights which can be used when fitting least-squares lines to the estimates, a formula for computing the variance of $Z_{q\cdot s}$ is required. Here it is assumed that the C_{ik} are pairwise independent and have a common variance, σ^2. The variance of $Z_{q\cdot s}$ is

$$\operatorname{var}(Z_{q\cdot s}) = \frac{1}{m_q^2} \sum_{k=1}^{M} I_k(q) \operatorname{var}(Z_{qks}) + \frac{2}{m_q^2} \sum_{k<\ell} I_k(q)I_\ell(q) \operatorname{cov}(Z_{qks}, Z_{q\ell s}). \tag{8}$$

For expressing the first term of (8) we use

$$\begin{aligned}\operatorname{var}(Z_{qks}) = {} & \frac{1}{a_{ks}^2} \sum_{i=1}^{N} I_s(i)I_k(i) \operatorname{var}(Z_{is}) + \frac{1}{a_{ks}^2} \sum_{i=1}^{N} I_s(i)I_k(i) \operatorname{var}(Z_{ik}) \\ & + \operatorname{var}(Z_{qk}) \\ & + \frac{2}{a_{ks}^2} \sum_{i<j} I_s(i)I_k(i)I_s(j)I_k(j) \left[\operatorname{cov}(Z_{is}, Z_{js}) + \operatorname{cov}(Z_{ik}, Z_{jk})\right] \\ & - \frac{2}{a_{ks}} \sum_{i=1}^{N} I_s(i)I_k(i) \operatorname{cov}(Z_{ik}, Z_{qk}) \end{aligned} \tag{9}$$

as well as

$$\begin{aligned} \operatorname{var}(Z_{ik}) &= E(Z_{ik}^{2}) - \left[E(Z_{ik})\right]^{2} \\ &= \frac{n_k - 1}{n_k}\,\sigma^{2} + \left[\rho_i - \frac{1}{n_k}\sum_{h=1}^{N} I_k(h)\rho_h\right]^{2} - \left[\rho_i - \frac{1}{n_k}\sum_{h=1}^{N} I_k(h)\rho_h\right]^{2} \\ &= \frac{n_k - 1}{n_k}\,\sigma^{2} \end{aligned} \tag{10}$$

and

$$\begin{aligned} \underset{i\neq j}{\operatorname{cov}}(Z_{ik}, Z_{jk}) &= E(Z_{ik}Z_{jk}) - E(Z_{ik})E(Z_{jk}) \\ &= \left[\rho_i - \frac{1}{n_k}\sum_{h=1}^{N} I_k(h)\rho_h\right]\left[\rho_j - \frac{1}{n_k}\sum_{h=1}^{N} I_k(h)\rho_h\right] \\ &\quad - \left[\rho_i - \frac{1}{n_k}\sum_{h=1}^{N} I_k(h)\rho_h\right]\left[\rho_j - \frac{1}{n_k}\sum_{h=1}^{N} I_k(h)\rho_h\right] - \frac{\sigma^{2}}{n_k} \\ &= -\frac{\sigma^{2}}{n_k}\,. \end{aligned} \tag{11}$$

Also, note that under the independence assumption

$$\underset{k\neq \ell}{\operatorname{cov}}(Z_{ik}, Z_{j\ell}) = 0. \tag{12}$$

For the second term of (8),

$$\operatorname{cov}(Z_{qks}, Z_{q\ell s}) = E(Z_{qks}Z_{q\ell s}) - E(Z_{qks})E(Z_{q\ell s}). \tag{13}$$

Using some of the previously stated results to evaluate the expectations in (13),

$$\underset{k\neq \ell}{\operatorname{cov}}(Z_{qks}, Z_{q\ell s}) = \sigma^{2}\left(\frac{a_{k\ell s}}{a_{ks}a_{\ell s}} - \frac{1}{n_s}\right), \tag{14}$$

where

$$a_{k\ell s} = \sum_{i=1}^{N} I_k(i) I_\ell(i) I_s(i).$$

Then, substituting (9), (10), (11), (12), and (14) into (8), we obtain

$$\mathrm{var}(Z_{q\cdot s}) = \frac{\sigma^2}{m_q^2}\left\{\sum_{k=1}^{M} I_k(q)\frac{1}{a_{ks}}\left[\frac{n_s - a_{ks}}{n_s} + a_{ks} + 1 - 2 I_s(q)\right]\right.$$

$$\left. + 2\sum_{k<\ell} I_k(q) I_\ell(q)\left[\frac{a_{k\ell s}}{a_{ks}a_{\ell s}} - \frac{1}{n_s}\right]\right\}. \qquad (15)$$

An unbiased estimate of $\mathrm{var}(Z_{q\cdot s})$ can be computed from (15) when σ^2 is replaced by its unbiased estimator, $\hat{\sigma}^2$, obtainable with analysis of variance techniques.

4. APPLICATION

Actual albacore catch and effort data have not yet been subjected to analysis with these methods. However, available data indicate that log relative fishing power can be estimated for about 200 vessels. Calculating the estimates and their variances will require extensive computation, a job well-suited to an electronic computer.

Experience Paper No. 13

THE CALIFORNIA ALBACORE FISHERY LOGBOOK SYSTEM

By

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Abstract

A voluntary logbook system combined with legal fish receipts (pink tickets) has been used successfully by the California Department of Fish and Game to obtain catch statistics for the California albacore fishery since 1954. This report describes the design of the logbook and the methods of distributing, collecting, editing, and machine processing the logs. Also briefly discussed is the potential application of these detailed logbook data to ecological studies as well as to studies of the fishery's dynamics.

LE SYSTEME DES JOURNAUX DE PECHE EMPLOYE DANS LA PECHE CALIFORNIENNE DE L'ALBACORE

Résumé

Depuis 1954, le Department of Fish and Game de Californie combine avec succès, pour rassembler les statistiques des prises des pêcheries d'albacore de Californie, deux systèmes: journaux de pêche tenus volontairement par les pêcheurs, et états remplis obligatoirement par les marchands de poissons, appelés couramment "feuilles roses". La présente communication décrit le journal de pêche utilisé et les méthodes employées pour sa distribution et pour le rassemblement, la mise au point et le traitement mécanographique des données. Elle examine en outre brièvement l'application possible des renseignements détaillés ainsi obtenus aux enquêtes écologiques et aux études sur la dynamique de cette pêche.

EL SISTEMA ESTADISTICO DEL DIARIO DE PESCA PARA LA ALBACORA EN CALIFORNIA

Extracto

El Departamento de Caza y Pesca de California ha implantado desde 1954, con éxito satisfactorio, un sistema voluntario de diario de pesca, combinado con la entrega de resguardos (de color rosa), para obtener estadísticas de captura de la albacora. En este informe se describe el modelo del diario y los métodos de distribución, acopio, edición y elaboración mecánica de las fichas. También se exponen brevemente las posibilidades de aplicación de los pormenores de este registro a los estudios ecológicos y de la dinámica pesquera.

1 INTRODUCTION

Adequate catch statistics are basic and fundamental to every study of exploited fish populations. Among the most important of these statistics are details concerning the quantity, locality, and date of the catch as well as the amount of effort per unit of time required to make the catch. California's albacore logbook system evolved as a means of obtaining these vital data.

A California law, instituted in 1916, has required all fish dealers to complete a receipt showing, among other things, the weight, and catch origin by species for each purchase of fish. The triplicate copy of this receipt, popularly known as the "pink ticket", is the Department's record of the transaction and has become the foundation for compiling all California fishery statistics (California, Bureau of Marine Fisheries, 1952).

For fisheries pursued on a daily basis, pink tickets adequately provide the basic statistics. The fishery for albacore (Thunnus germo) has such a wide range in both time and space that total weight of the catch is the most we can hope to glean from the pink tickets. Since 1954, the California Department of Fish and Game has used voluntary logbooks coordinated with pink tickets to secure basic catch data for the California albacore fishery.

2 LOGBOOK DESIGN

Until 1951, albacore catch statistics were gathered irregularly as time and manpower allowed. During the 1951 season, one man was assigned full time to gather general catch data by interviewing vessel captains at the time fish were landed. Analysis of this general information clearly indicated the need for more specific catch data. A logbook seemed the most promising tool for meeting this need.

Prior to adopting the logbook system, we summarized albacore catches by one-degree latitude and longitude blocks. This was done for simplicity: the equal areas were small enough to yield details of the fishery yet large enough to allow fishermen some freedom in determining their position. Thus the basic design of the log became a chart of the fishing area divided into one-degree blocks of latitude and longitude (Fig. 1). The user has only to plot the course of his journey on the scaled-down charts in his logbook and indicate appropriate fishing areas with numbers. A section of each log sheet is reserved for the user to record chronologically his daily catches by designating each fishing area numerically. Space is also provided on the log to identify the boat and the specific trip.

Unlike fish receipts, the logbooks have no legal status and their use has been strictly voluntary. For this reason, the requested information was limited to what we felt was absolutely necessary, asking the fisherman to add only sea-surface temperatures to the basic fishing data.

In 1954, a few experimental logbooks were mimeographed and distributed to several members of the albacore fleet. The initial response and success resulted in our printing a stock of 2,000 logbooks to distribute beginning with the 1955 season. Their use has continued to the present time.

Since the California albacore fishery ranges from central Baja California (Mexico) north to Canada, we provide two charts, one for the northern and one for the southern fishing grounds. A book (Fig. 1) consists of 25 duplicate charts for each area or a total of 100 pages. Each pair of pages is provided with a sheet of carbon paper so that one copy of the log may be retained and the other forwarded to the California State Fisheries Laboratory, Terminal Island. Several postage-prepaid envelopes are enclosed with each book to insure the return of completed logs. Many logs are returned via the mail, but by far the greatest number is picked up from the fisherman by field personnel at the major landing ports. This method has the advantage of making certain the log is complete and allows a first-hand opportunity to resolve inconsistencies.

Nearly 1,000 logbooks have been issued to willing vessel operators since the program's inception in 1955. To supplement the logbooks, we have prepared separate log sheets for field personnel to transpose fishing data from vessels maintaining suitable logs but not using the California logbook. Many vessel operators have been willing to make their catch data available but desire to keep their own records. By using personal contact and the log-copy sheets we obtain a great deal more catch data than if we relied on logbooks alone.

3 EDITING COMPLETED LOGS

Editing the logs collected during a season's fishery is the most time-consuming job in

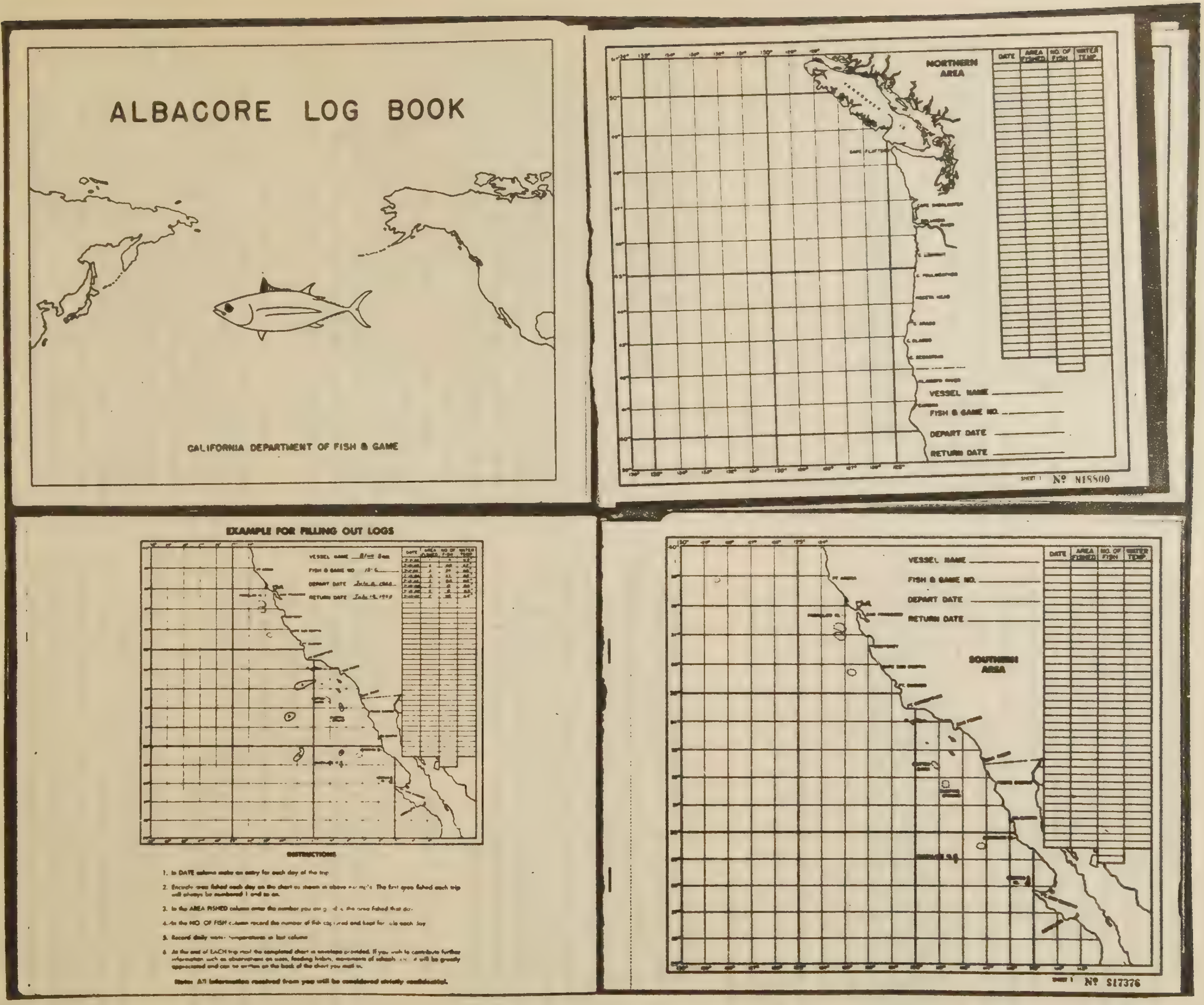

ALBACORE LOG BOOK
CALIFORNIA DEPARTMENT OF FISH & GAME
NORTHERN AREA
DATE
AREA FISHED
NO. OF FISH
WATER TEMP.
VESSEL NAME
FISH & GAME NO.
DEPART DATE
RETURN DATE
Nº N18800
EXAMPLE FOR FILLING OUT LOGS
INSTRUCTIONS
SOUTHERN AREA
Nº S17376

Fig. 1. A California albacore fishery logbook showing the cover, instructions and charts of southern and northern fishing areas. (Photo by J. W. Schott)

the system. Logs are gathered each season from 200 to 500 boats that have fished between 5,000 and 10,000 days. Because all raw log data are ultimately punched on IBM cards, editing must be done neatly so clerical personnel unfamiliar with the data can accomplish the key punching.

Editing begins with a careful inspection of each log for completeness. Often there are deliberate or accidental ommissions of days within a trip which the editor may correct; or he may reject the entire log. For all acceptable logs, daily fish catches are totalled and assigned to the proper one-degree block determined by the latitude and longitude at the southeast corner of the indicated block. Decisions must be made on where to assign catches made in overlapping fishing areas and along lengthy trolling tracks covering several one-degree blocks. These steps constitute preliminary editing.

When the fish receipts (pink tickets) become available, the weight of fish for the trip is entered on its log. The month each load of fish was landed is also placed on the appropriate log at this time, for use in determining catch dates from the landing figures. The average weight of an individual fish for the catch is determined by dividing the number of fish (reported by the fisherman on his log) into the weight of the load (reported on the pink ticket). Additional logs are rejected at this stage of editing because of inconsistent average weights or the absence of a pink ticket. The total number of rejects is generally quite small (5 percent or less) and usually is because a fisherman misunderstood directions for completing his logs. Rejects are usually highest during seasons marked by economic difficulties when fish are sold through many irregular channels. When serial trip numbers and registered-vessel lengths have been assigned and each log is carefully rechecked, the season's accumulation of logbook data is ready for IBM processing (Fig. 2).

4 MACHINE PROCESSING AND TABULATION

All the numerical data for every day of fishing are punched on standard IBM cards. Daily catch weights are calculated from the average weight and automatically placed on each card by an IBM-1620 electronic computer. This completes the punching process. IBM tabulating machines can now mechanically summarize the data in many different combinations. Currently we are using 10 different reports or summarizations of the punchcard data (Fig. 3a and b).

4.1 Boat listing tabulation

One report serially lists all of the catch data for each trip made by each vessel; the information is arranged in ascending order by Fish and Game license plate numbers (each vessel upon registering with the Department is issued a numbered license and no two vessels have the same number). This report forms the basis for subsequent tabulations and affords an opportunity to check against the individual logs.

4.2 Tabulations by origin blocks

Three separate tabulations are made by the one-degree block origins. In one, numbers and total weights of fish are presented for each degree Fahrenheit of surface temperature for each day of the season. Temperatures are recorded in Fahrenheit because it is the most commonly used and accepted measure by our fishermen. In another, for each day of the month the number of boats and their catch are totalled. The third summarizes the catch and number of days fished (effort) for each month of the season.

4.3 Tabulations by sea temperature

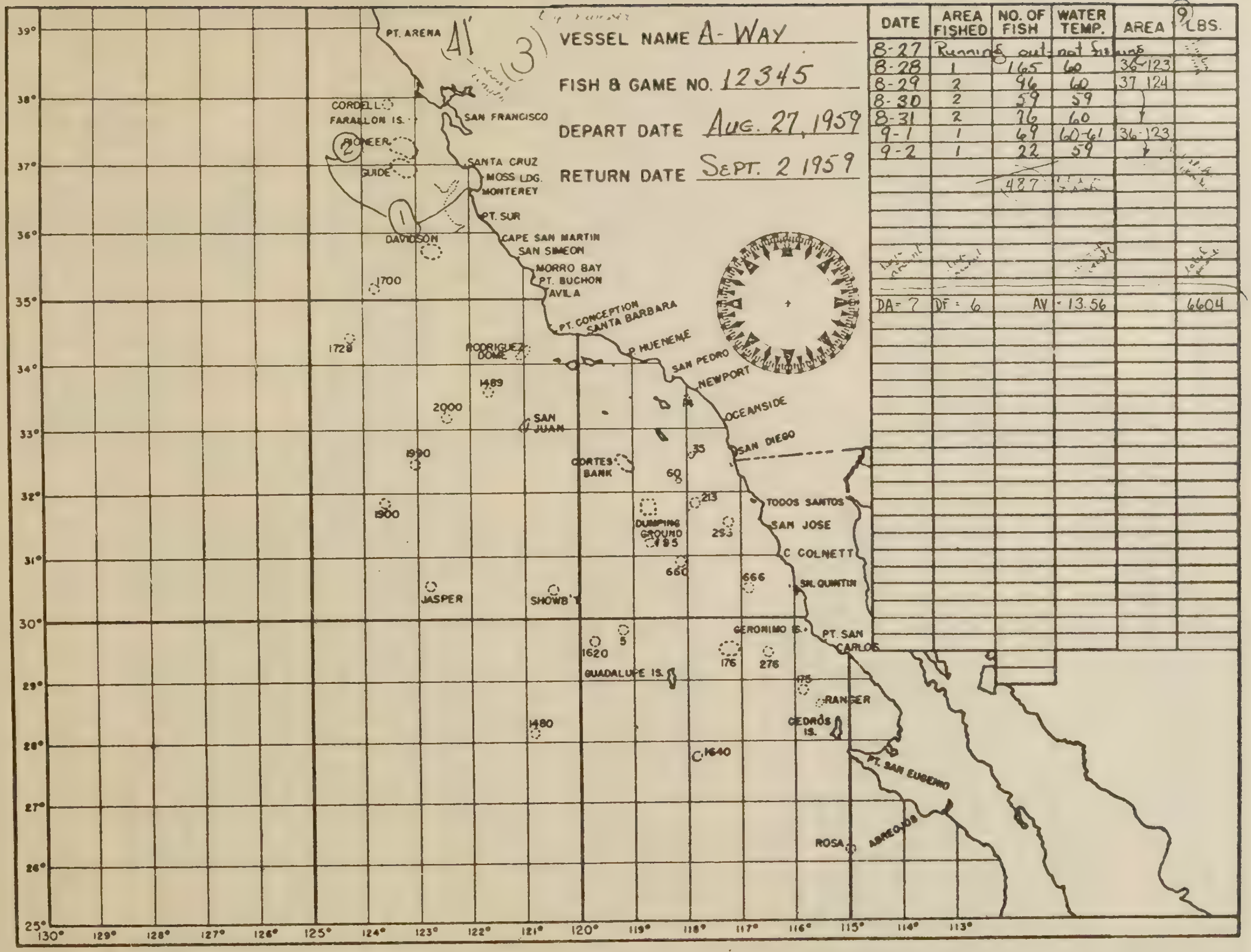
Two tabulations are directly concerned with the sea-surface temperatures reported on the logs. These are monthly and seasonal summaries of catch by one-degree Fahrenheit intervals.

4.4 Tabulation of trip lengths and fishing days

Two other tabulations are in the form of frequency distributions. One is a summary distribution of the number of boats for each reported period of absence from port (trip length in days) and the other is a summary distribution of boats for each reported number of fishing days (trip length less travel time).

4.5 Miscellaneous tabulations

The remaining two tabulations do not fall into any general classification. The first of these relates the monthly catches to the monthly landings and determines both the catch date and total catch for each of the sample


PT. ARENA
41
3
1
2
CORDELL
FARALLON IS.
PIONEER
GUIDE
DAVIDSON
SAN FRANCISCO
SANTA CRUZ
MOSS LDG.
MONTEREY
PT. SUR
CAPE SAN MARTIN
SAN SIMEON
MORRO BAY
PT. BUCHON
AVILA
PT. CONCEPTION
SANTA BARBARA
P. HUENEME
SAN PEDRO
NEWPORT
OCEANSIDE
SAN DIEGO
TODOS SANTOS
SAN JOSE
C COLNETT
SN. QUINTIN
GERONIMO IS.
PT. SAN CARLOS
RANGER
CEDROS IS.
PT. SAN EUGENIO
ABREOJOS
ROSA
1700
1728
RODRIGUEZ DOME
1489
2000
SAN JUAN
1990
1900
CORTES BANK
35
60
213
DUMPING GROUND
185
293
660
666
JASPER
SHOWB'T
1620
5
GUADALUPE IS.
176
276
175
1480
1640
39°
38°
37°
36°
35°
34°
33°
32°
31°
30°
29°
28°
27°
26°
25°
130°
129°
128°
127°
126°
125°
124°
123°
122°
121°
120°
119°
118°
117°
116°
115°
114°
113°

VESSEL NAME A- WAY

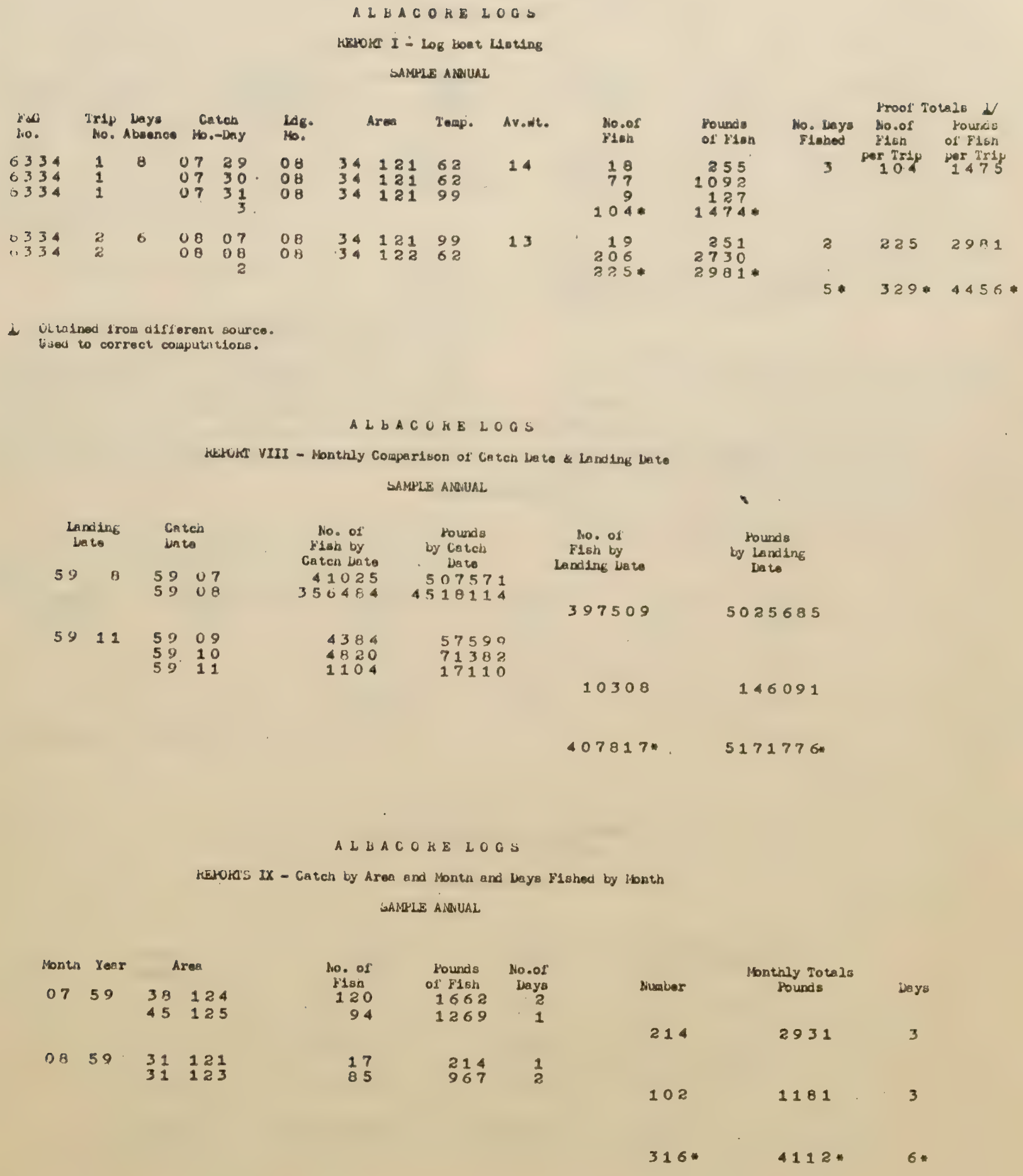
FISH & GAME NO. 12345

DEPART DATE AUG. 27, 1959

RETURN DATE SEPT. 2 1959

DATE	AREA FISHED	NO. OF FISH	WATER TEMP.	AREA	9 LBS.
8-27	Running out not fishing				
8-28	1	165	60	36-123	
8-29	2	96	60	37 124	
8-30	2	59	59		
8-31	2	76	60		
9-1	1	69	60-61	36-123	
9-2	1	22	59		
		487			
DA= 7	DF = 6	AV	- 13.56		6604

Fig. 2. An example of a completed albacore log sheet ready for IBM processing. Encircled data have been entered by the Editor. (Photo by J. W. Schott)



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                                ALBACORE LOGS

                          REPORT I - Log Boat Listing

                                SAMPLE ANNUAL

                                                                                          Proof Totals 1/
F&G   Trip  Days    Catch    Ldg.    Area     Temp.  Av.wt.    No.of     Pounds   No. Days  No.of    Pounds
No.   No. Absence  Mo.-Day   No.                               Fish      of Fish   Fished   Fish     of Fish
                                                                                            per Trip per Trip
6334   1     8     07 29     08    34 121     62      14         18        255       3       104      1475
6334   1           07 30     08    34 121     62                 77       1092
6334   1           07 31     08    34 121     99                  9        127
                       3                                        104*      1474*

6334   2     6     08 07     08    34 121     99      13         19        251       2       225      2981
6334   2           08 08     08    34 122     62                206       2730
                       2                                        225*      2981*
                                                                                     5*       329*     4456*

1/ Obtained from different source.
   Used to correct computations.
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                                ALBACORE LOGS

          REPORT VIII - Monthly Comparison of Catch Date & Landing Date

                                SAMPLE ANNUAL

  Landing     Catch          No. of       Pounds          No. of          Pounds
   Date        Date          Fish by      by Catch        Fish by         by Landing
                            Catch Date     Date         Landing Date        Date
 59   8      59 07           41025        507571
             59 08          356484       4518114
                                                          397509           5025685

 59  11      59 09            4384         57590
             59 10            4820         71382
             59 11            1104         17110
                                                           10308            146091


                                                          407817*          5171776*
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                                ALBACORE LOGS

             REPORTS IX - Catch by Area and Month and Days Fished by Month

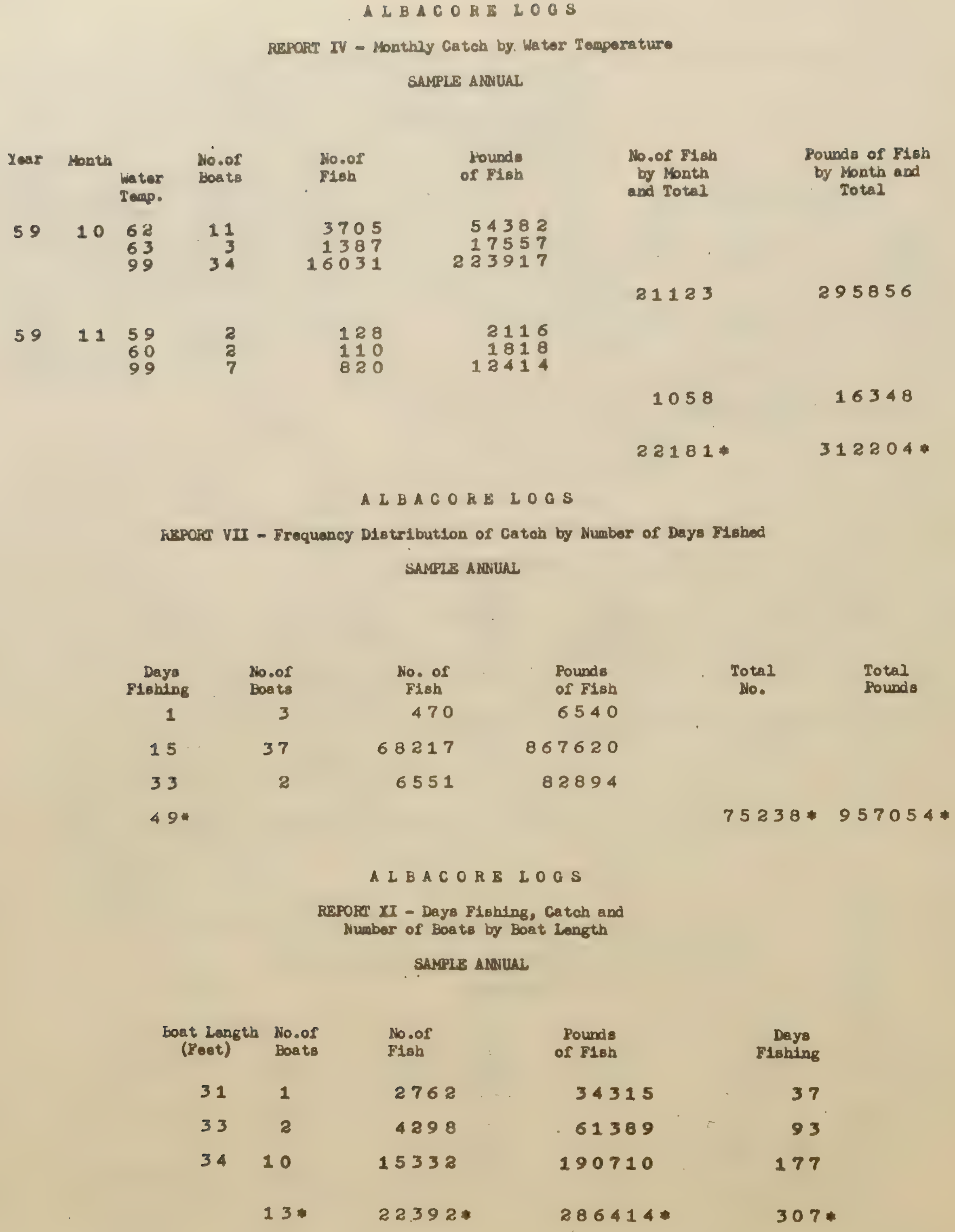
                                SAMPLE ANNUAL

Month  Year    Area          No. of     Pounds    No.of                   Monthly Totals
                              Fish     of Fish    Days          Number        Pounds         Days
 07    59     38 124          120        1662       2
              45 125           94        1269       1
                                                                 214           2931            3

 08    59     31 121           17         214       1
              31 123           85         967       2
                                                                 102           1181            3


                                                                 316*          4112*           6*
```

Fig. 3a. Some examples of the IBM tabulated reports derived from albacore logbook data. (Photo by J. W. Schott)



ALBACORE LOGS

REPORT IV - Monthly Catch by Water Temperature

SAMPLE ANNUAL

Year	Month	Water Temp.	No.of Boats	No.of Fish	Pounds of Fish	No.of Fish by Month and Total	Pounds of Fish by Month and Total
59	10	62	11	3705	54382		
		63	3	1387	17557		
		99	34	16031	223917		
						21123	295856
59	11	59	2	128	2116		
		60	2	110	1818		
		99	7	820	12414		
						1058	16348
						22181*	312204*

ALBACORE LOGS

REPORT VII - Frequency Distribution of Catch by Number of Days Fished

SAMPLE ANNUAL

Days Fishing	No.of Boats	No. of Fish	Pounds of Fish	Total No.	Total Pounds
1	3	470	6540		
15	37	68217	867620		
33	2	6551	82894		
49*				75238*	957054*

ALBACORE LOGS

REPORT XI - Days Fishing, Catch and Number of Boats by Boat Length

SAMPLE ANNUAL

Boat Length (Feet)	No.of Boats	No.of Fish	Pounds of Fish	Days Fishing
31	1	2762	34315	37
33	2	4298	61389	93
34	10	15332	190710	177
	13*	22392*	286414*	307*

Fig. 3b. Some examples of the IBM tabulated reports derived from albacore logbook data. (Photo by J.W. Schott)

monthly landings. Since many vessels extend their catches over one-, two-, or three-month periods their single landing receipt can be prorated into the months fish actually were caught. The last tabulation yields a distribution of days fishing, catch, and number of boats by vessel lengths. We use this report to study fishing success for various sized vessels and to determine if our sample represents the size distribution of the entire fleet.

5 USE OF LOGBOOK DATA

One reason for the success of the logbook system is the respect shown for the confidential nature of these data. The entire system is voluntary and totally dependent upon cooperation between the vessel owners or operators and the Department. Every person using an albacore logbook is assured that the privacy of his records will be preserved.

The logbooks sample about 20 to 25 percent of the total albacore poundage landed and about 40 percent of the skippers (boats) that fish during a season complete at least one log. We believe that because of its size this sample represents the activities of the entire albacore fleet at all California ports. With certain exceptions, we assign statewide landings to one-degree blocks by the correct month of catch in the direct proportion indicated by the logbook sample. Heavy purse-seiner landings of albacore in 1960 and 1961 exemplify a situation in which we did not assign detailed catch localities to the total landings. We do not feel that purse seiners are typical albacore boats because their effort is not comparable, therefore we subtract their landings from the total prior to making any assignment.

With the California fleet catch and effort for each season assigned to one-degree blocks by month of catch, we have a firm foundation for studying the dynamics of the albacore fishery as well as invaluable information for making ecological studies of this valuable species. Presently we are making every effort to analyze a backlog of data so it can be published and made available to all interested individuals and organizations.

Experience Paper No. 14

CHANGES IN AVAILABILITY OF ALBACORE IN THE EASTERN PACIFIC OCEAN 1952 and 1958

by

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Abstract

Environmental conditions and albacore catch and landing records were examined for 1952 and 1958. Changes in distribution of albacore in the coastal waters of North America for these two years appear to be related to differences in oceanographic features which were apparent not only over the region of the fishery but over a large portion of the central north Pacific Ocean. The possibility that differences in oceanographic conditions were related to contrasting atmospheric features for the two years is discussed.

VARIATIONS DES DISPONIBILITES EN GERMONS DANS LA PARTIE EST DE L'OCEAN PACIFIQUE, 1952 ET 1958

Résumé

On a examiné pour 1952 et 1958 les conditions du milieu ainsi que les statistiques des prises et des apports de germons. La comparaison entre ces deux années a fait apparaître dans la répartition des germons des eaux côtières d'Amérique du Nord des modifications semblant en rapport avec des différences dans les caractéristiques océanographiques, qui se sont manifestées non seulement sur les lieux de pêche, mais dans une large portion de la partie centrale du Pacifique Nord. Le document examine la possibilité que ces différences soient rattachées à la diversité des conditions atmosphériques de ces deux années.

VARIACIONES EN LA DISPONIBILIDAD DE LA ALBACORA EN EL PACIFICO ORIENTAL EN 1952 Y 1958

Extracto

Examinados los datos de captura y desembarque de albacora y las condiciones ambientales de 1952 y 1958, resulta que las variaciones experimentadas durante esos dos años por la distribución de la albacora en las aguas costeras de Norteamérica guardaban relación con las variables características oceanográficas, manifestadas no sólo en la zona de la pesquería, sino también sobre una vasta extensión del Pacífico centro-septentrional. Se discute aquí la posibilidad de correlación entre las diferentes condiciones oceanográficas y las contrastantes características atmosféricas de aquellos dos años.

1 INTRODUCTION

Landings of albacore (Thunnus germo) in United States ports over the decade 1950 to 1959 ranged from 26.72 million pounds in 1954 to 71.60 million pounds in 1950. More striking than the fluctuation in total landings, however, is the variation that has occurred in distribution of albacore in North American coastal waters as deduced from landing and catch distribution records.

Annual variations in landings of albacore in United States ports depend upon abundance of albacore in the northeastern Pacific Ocean, fishing effort expended to harvest this fish and its availability to the fisherman. For purposes of this paper, abundance is defined as the absolute number of individuals in a population, and availability as variation in catch not associated with abundance or fishing intensity, but rather with variation in environmental factors (Marr 1951).

Although variations in abundance probably affect the success of the fishery from year to year, assessment of the effect of changes of abundance on the albacore fishery has not yet been established; nor have investigations been conducted to assess the effect of annual variations in fishing intensity on the fishery. Recent studies, however, have shown that variations in the ocean climate alter distribution of albacore in the northeastern Pacific (Hester 1961; Radovich 1961; Johnson 1962) which in turn have affected availability for different regions over which the fishery is carried out. The intent here is to analyze environmental conditions and catch records for 1952 and 1958, years when changes in catch location of albacore were clearly evident (Fig. 1), and to suggest that changes in availability at the southern and northern ranges of the fishery in coastal waters of North America may have been caused by differences in environmental conditions for the two years. For purposes of this paper, a southern fishery is defined as that carried out south of the International Border between Mexico and the United States, and a northern fishery as that occurring north of the California-Oregon border.

2 ALBACORE FISHERIES AND MIGRATIONS IN THE NORTH PACIFIC

Recent tagging experiments indicate that the albacore of the north Pacific Ocean belong to one population (Otsu 1960; Clemens 1961). During a period of a year, parts of this population are fished throughout temperate waters. The Japanese live-bait fishery occurs in coastal waters of Japan during the spring and early summer and follows closely the Japanese winter longline fishery of the western and central north Pacific (Van Campen 1960). The live-bait and troll fishery of the north eastern Pacific occurs in coastal waters of North America in the summer and autumn (Clemens 1955).

Otsu and Uchida (1961) postulate a center of abundance in the central north Pacific through and from which the albacore migrate into the three fisheries. During its lifetime an individual albacore may have been subjected to all three fisheries. According to McGary, Graham and Otsu (1961) the eastward migration in spring and summer toward the American coast is related to the 55° to 65°F band of water of the Transition Zone defined by Hida (1957) as "an area of mixed fauna and variable biomass between the Subtropic and Subarctic Zones". Clemens (1955) has found that first arrival of migrants into the American fishery usually occurs in June. Craig and Caneday (1962) believe that the early season migration may take place in the California Current, which is the eastern southward-flowing part of the large clockwise circulatory system of the north Pacific. Because water in the surface layer is transported from north to south in this current, it can be identified off southern California and Baja California by its low temperature-low salinity characteristics. Considerable variations exist from year to year in the strength of the California Current (Reid, Roden, and Wyllie 1958), and the southern limit of the albacore fishery each year appears to be related in part to these variations. In years when the current is strong, that is, when low temperature-low salinity water penetrates farther to the south than usual, albacore are found farther to the south. In years of a weak current the albacore appear farther to the north.

Clemens (1961) has found that, as a rule, the southern extent of best fishing is limited by about the 66° or 67°F isotherm. Because of lack of adequate fishing records, extent of the northern fishery off Oregon and Washington in relation to the environment is more difficult to define. Johnson (1960) and Flittner (1961) have found from Navy vessels cooperating with the U.S. Bureau of Commercial Fisheries in a trolling program that the northward advance of 59° to 60°F water is accompanied by northward distribution of albacore; and Alverson (1961), summarizing north Pacific albacore surveys,

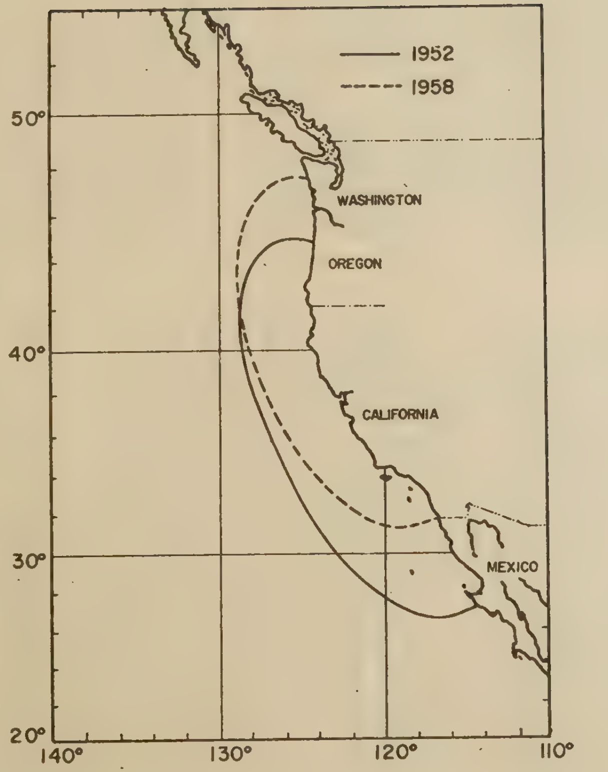
1952
1958
WASHINGTON
OREGON
CALIFORNIA
MEXICO
50°
40°
30°
20°
140°
130°
120°
110°

Fig. 1 General region of the albacore fishery in coastal waters of the United States for 1952 and 1958

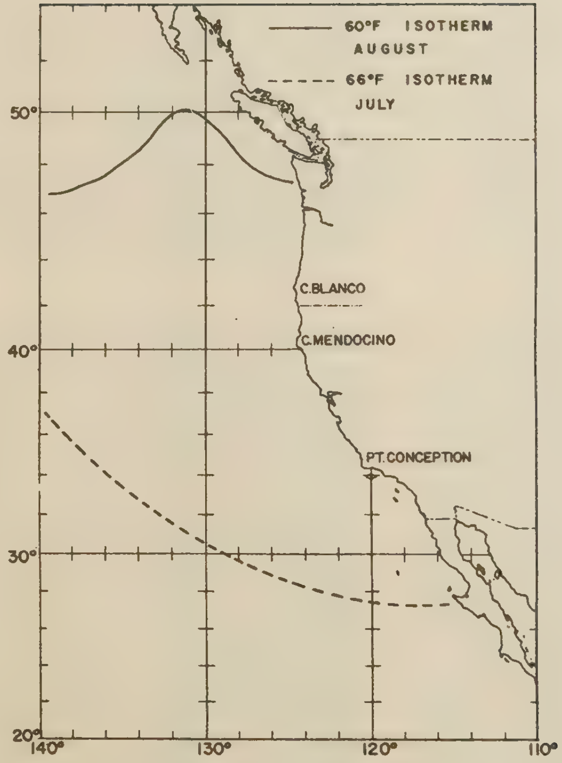
60°F ISOTHERM AUGUST
66°F ISOTHERM JULY
C.BLANCO
C.MENDOCINO
PT.CONCEPTION
50°
40°
30°
20°
140°
130°
120°
110°

Fig. 2 Normal southern limit of 66°F isotherm in July and normal northern limit of 60° F isotherm in August based on sea temperature data for 1947 to 1958

found best fishing occurred in about 60°F water.

The most southern limit of the fishery usually occurs in July or August (Clemens 1955); in July the 66° F isotherm normally intersects the North American mainland at about latitude 27° N (Fig. 2). The most northern extent of the fishery usually occurs in August at which time the 60° F isotherm nears 50° N at about 130° W. The commercial fishery for albacore to the north, however, is conducted inshore of 130° W; the 60° isotherm in the general region of the fishery reaches about 47° N (Fig. 2).

3 SOUTHERN FISHERY, 1952 and 1958

Over the ten-year period 1950 to 1959, an average of 16.26 million pounds of albacore have been taken from south of the International Border (Table I). The highest landings from that area for the ten years occurred in 1952 when 26.70 million pounds were landed. Clemens (1955) shows that in 1952 albacore were taken in abundance as far as four hundred miles south of the border. In contrast to the favorable fishery of 1952, the fishery in 1958 was nearly a complete failure; only 0.72 million pounds were landed from south of the border. Catch distribution records are not available for 1958 but fishermen have indicated that the fishery barely penetrated the region south of the border.

The difference in landings for 1952 and 1958 for the region south of the border was accompanied by markedly different oceanographic conditions. In July 1952, 10 m water temperatures were much colder than the 1950 to 1959 average. Off Punta Eugenia, temperatures were as much as 8° F colder than the average (Fig. 3). The "cold" water was accompanied by salinity values that ranged considerably below average. The combination of low temperature-low salinity water suggests presence of California Current water. In July 1958, conditions were opposite; both temperatures and salinities were for the most part above average (Fig. 3), which suggests reduced influence of California Current water.

4 NORTHERN FISHERY, 1952 AND 1958

Although catch distribution records for the coastal region north of the California-Oregon border are not available, indication of the success and range of the fishery from that region can be obtained by examination of landing records. In 1952, only 2.76 million pounds of albacore were landed in Oregon-Washington ports as against 11.26 million pounds in 1958 (Table I). Furthermore, the fact that over a million pounds were taken by boats operating north of the California-Oregon border in 1958 and landed in California ports, as opposed to no landings in this category in 1952, is suggestive of a more northern fishery in 1958 (Table I).

Statements in the literature also support a more northern fishery in 1958 than in 1952. An exploratory fishery cruise in 1952 by the research vessel John N. Cobb found albacore scarce throughout coastal waters of Oregon and Washington and offshore to about five hundred miles (Schaefers 1953). Pacific Fisherman Yearbook (1953) notes that albacore fishing in 1952 off the coast of Washington was virtually blank and that Oregon waters yielded little. In 1958, however, fishermen found the best albacore run in years off Pacific northwest states (Pacific Fisherman Yearbook 1959); in fact, a few albacore were taken in the Gulf of Alaska by vessels trolling for salmon (Pacific Fisherman 1958).

Extensive oceanographic data are not available for 1952 and 1958 for coastal waters of Oregon and Washington. Oceanographic conditions for the two years as indicated by sea surface temperatures, however, were markedly different. In 1952 when the fishery was poor, August temperatures were appreciably below average, and in 1958, when the fishery was a success, August temperatures were above average (Fig. 4).

5 DISCUSSION

Oceanographic conditions that may have caused the differences in distribution of albacore in 1952 and 1958 were established well before the fishing season began in July. Ten-meter temperature and salinity anomalies for the region south of the International Border for April 1952 and April 1958 were similar to those in July (Fig. 3). Sea-surface temperature anomaly charts of coastal regions of North America show that the first six months of 1952 was characterized by "cold" water in the northeastern Pacific, whereas for the first half of 1958 "warm" water was widespread (Johnson 1961).

Differences in oceanographic conditions between the two years were not limited to the area contiguous to North America but occurred also in much of the central north Pacific Ocean.

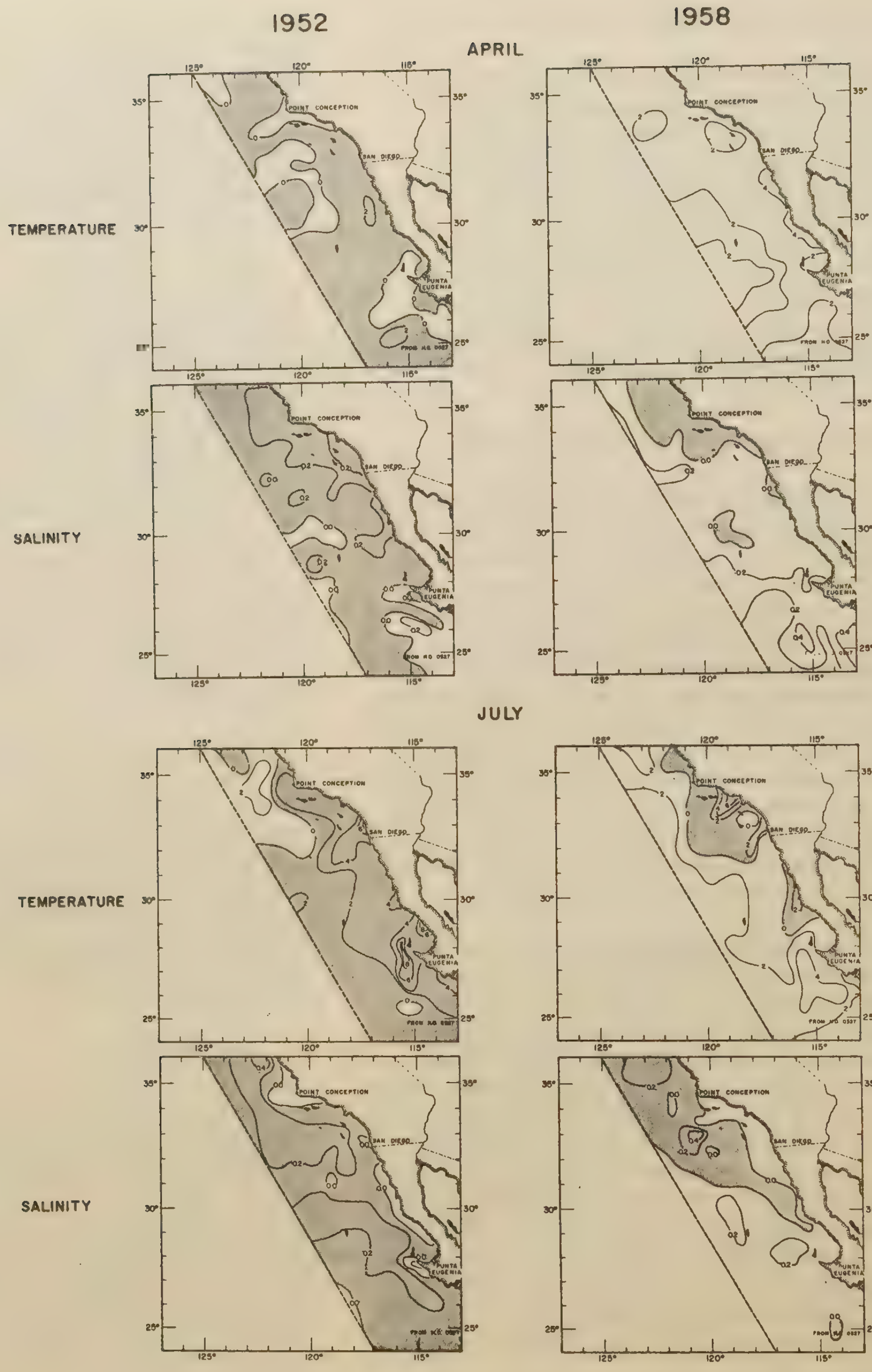
1952
1958
APRIL
JULY
TEMPERATURE
SALINITY
TEMPERATURE
SALINITY
125°
120°
115°
35°
30°
25°
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
FROM H.O. 0527

Fig. 3 Ten-meter temperature and salinity anomalies for April and July, 1952 and 1958, based on 1950 to 1959 averages. Contour interval for temperatures 2°F and for salinities 0.2°/oo. Shaded areas indicate temperatures and salinities below average.

Table I

Landings of albacore in United States ports, in millions of pounds, 1950 to 1959[1/]

Year	Landings in California from south of International Border between Mexico and United States	Landings in California from California waters	Landings in California from north of California-Oregon Border	Landings in Oregon and Washington	Total U.S. landings
1950	23.60	38.14	0.08	9.78	71.60
1951	17.62	13.28	0.01	3.44	34.35
1952	26.70	23.10	0.00	2.76	52.56
1953	20.49	13.30	0.05	0.81	34.65
1954	11.82	14.29	0.00	0.61	26.72
1955	19.69	9.31	0.00	0.70	29.70
1956	21.06	15.87	0.12	4.28	41.33
1957	20.91	22.61	0.00	3.06	46.58
1958	0.72	25.39	1.08	11.26	38.45
1959	0.00	32.52	0.22	13.54	46.28
Average	16.26	20.78	0.16	5.02	42.22

[1/] Source - Calif. Dept. Fish and Game, Marine Resources Operations; Pacific Fisherman Yearbook 1961.

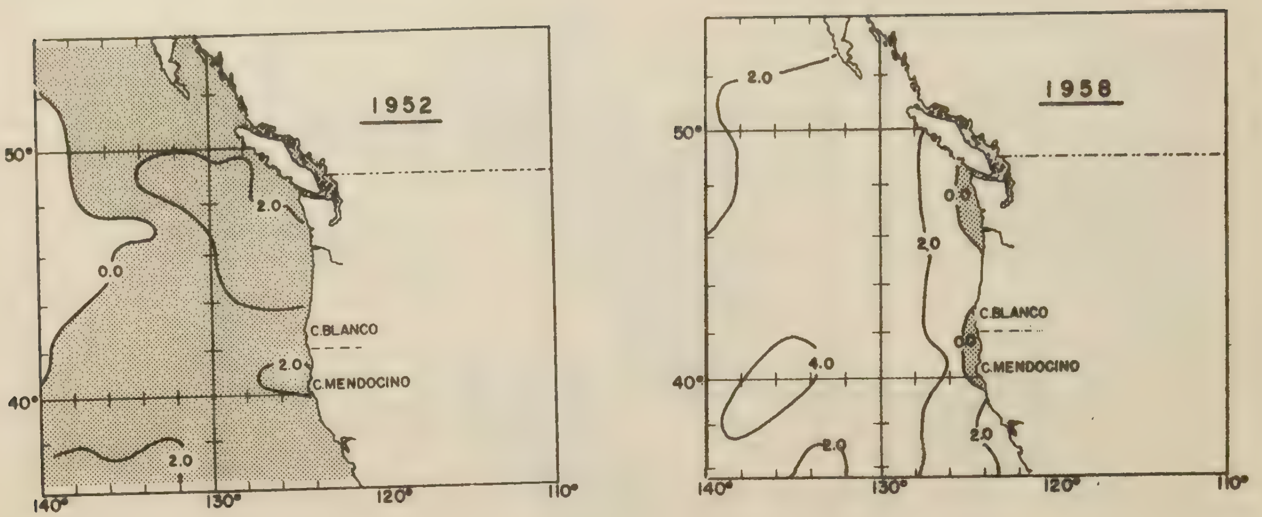
1952
50°
40°
2.0
0.0
C.BLANCO
2.0
C.MENDOCINO
2.0
140°
130°
120°
110°
1958
2.0
50°
0.0
2.0
C.BLANCO
0.0
C.MENDOCINO
4.0
40°
2.0
2.0
140°
130°
120°
110°

Fig. 4 Sea-surface temperature anomalies for August 1952 and 1958, based on 1947 to 1958 average. Contour interval 2°F. Shaded areas colder than average.

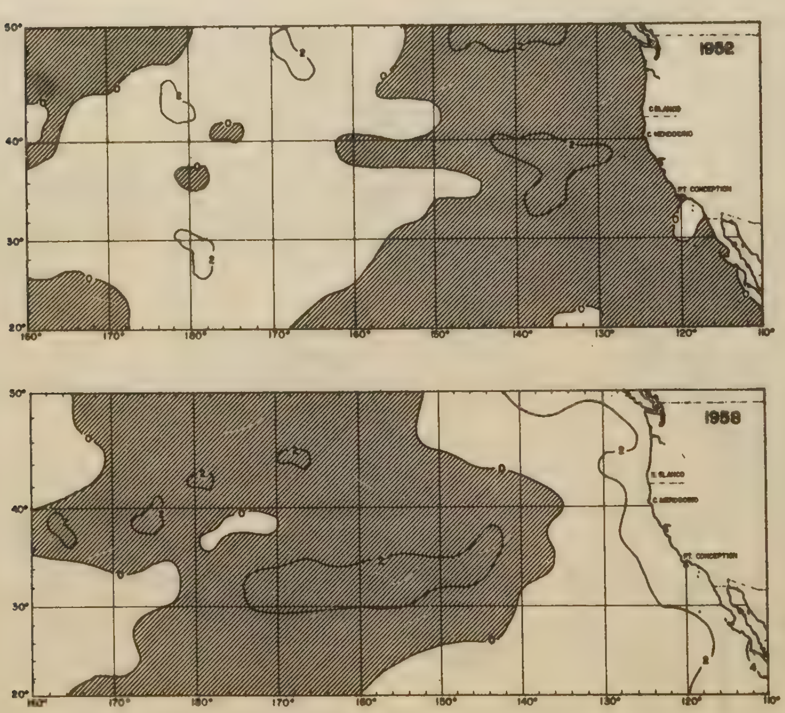
1952
50°
40°
30°
20°
C.BLANCO
C.MENDOCINO
PT. CONCEPTION
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
1958
50°
40°
30°
20°
C.BLANCO
C.MENDOCINO
PT. CONCEPTION
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°

Fig. 5 Sea-surface temperature anomalies for the central and eastern north Pacific Ocean for March, April, and May 1952 and 1958. Contour interval 2°F. Shaded areas colder than average.

In March, April and May of 1952, water warmer than the 1947-1958 mean covered a vast area of the central north Pacific. The anomaly in 1958 for the same general region was appreciably below normal (Fig. 5).

Over the past few years, increased emphasis has been placed on studies of the underlying causes of sea-temperature anomalies. Once these causes are understood, it may be possible to predict distribution of albacore on a broad-scale basis. Even now predictions of a general nature have been made possible because Roden and Reid (1961) have found that large-scale sea-temperature anomalies usually persist from three to six months.

Uda (1961) has studied albacore fisheries of the eastern and western Pacific and has recognized a reciprocal relation between the catch in the western Pacific and the catch in the eastern Pacific. He has explained this reciprocal relationship on sea-temperature trends which also were found by him to vary inversely. The variations in sea temperatures were further related to fluctuations in atmospheric pressure systems over the north Pacific (Uda 1960).

Examining sea temperature and sea level atmospheric pressure data for the north Pacific, Roden and Reid (1961) found agreement, in some cases, in anomalous pressures of the Pacific and anomalous temperatures. They noted that in January 1958 the central north Pacific was dominated by a large negative pressure anomaly in the region of the Aleutian low. From this they deduced increased southerly winds in the northeastern Pacific resulting in positive sea-temperature anomalies along the Pacific Coast of North America. Namias (1959) also noted the large positive sea-temperature anomaly in the eastern Pacific in 1958, and he concluded that this feature might be related to prevailing abnormalities in the atmospheric circulation caused by an eastern Pacific anticyclone much weaker than normal and prevailing westerly winds displaced much farther south than normal. He compared observed sea-temperature anomalies with computed wind-induced advective anomalies, using sea-level pressures, and found general agreement between the two in the winter 1957 to 1958 for the northeastern Pacific. Eber (1961) in further analysis of conditions in the winter 1957 to 1958 concurred that wind-induced advection may have resulted in the positive temperature anomaly.

Reid, Roden, and Wyllie (1958) indicate that for 1952 the north component of the wind computed from atmospheric pressure difference at 30°N between 110°-130°W was stronger than normal; and from an analysis of a system of pressure indices by Eber and Sette (1959), the conclusion can be drawn that winds over the California Current in 1952 were more intense than normal. These findings suggest increased advection of cold-low salinity water in the California Current which is consistent with data presented in Fig. 3 and movement of albacore to the south. Eber and Sette (1959) pointed out that their pressure indices for the winter months for 1946 to 1955 reflected a higher average intensity and more northerly mean position of the eastern north Pacific high compared with the two earlier decades.

Progress that has been made in recent years in relating distribution of albacore to broad-scale changes in the ocean climate, and the fact that some of these changes appear to have been related to variations in the atmosphere, lend credence to the prediction that those studying the time and space distribution of the albacore will turn increasingly to investigations of processes at the air-sea boundary. In the final analysis, the complex nature of changes in distribution of albacore appear inextricably related to both the ocean and the atmosphere.

6 ACKNOWLEDGEMENTS

Thanks are given to the Data Collection and Processing Group of Scripps Institution of Oceanography for use of sea-temperature and salinity averages (1950 to 1959) compiled from California Cooperative Oceanic Fisheries Investigation Reports, and to Oscar E. Sette, Gerald V. Howard, Laurence E. Eber, and Glen A. Flittner of the U. S. Bureau of Commercial Fisheries, for suggestions regarding the preparation of this report.

Experience Paper No. 15

STRUCTURE OF THE ALBACORE STOCK AND FLUCTUATION IN THE CATCH IN THE NORTH PACIFIC AREAS

By

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Abstract

Studies based on fishing logbooks, specimens sampled, tagging experiments and similar data of North Pacific albacores revealed:

(1) The fish are spawned in the North Equatorial Current and spend the immature stage in the North Pacific Current for a few years,

(2) are distributed densely enough to support commercial fisheries, and

(3) move widely between the eastern and the western parts of the Pacific. The exploited stock mainly consists of IV- and V-age. The recruitment and dispersion take place sometime around March.

Longline hooking-rate best represents the stock size in the fishing area. The year-class strength was estimated from age composition of catch.

The catch statistics examined for 1949 to 1959 indicated the year-class strength to be the factor governing the annual landings. Abundance of the stock is more important than availability for successful fishing in the northwestern Pacific. Environmental factors of the pre-exploited phase have to be considered for analyzing high fluctuations in the available stock size by year-class.

Since the stock size is the factor controlling albacore catches in the northwestern Pacific, determination of the recruitment is essential for successful prediction. Although the present information on the preceding stages is not highly reliable to forecast the subsequent stock sizes, methodological improvement will render the prediction more practical in future.

STRUCTURE DU STOCK DE THON GERMON ET FLUCTUATION DES APPORTS DE LA PECHE DANS LE PACIFIQUE NORD

Résumé

Des études basées sur des livres de pêche, des échantillonnages, des expériences de marquage et d'autres données, portant sur les thons germon du Pacifique Nord ont montré que:

(1) les poissons naissent dans le courant nord-équatorial et passent leur stade immature dans le courant nord-pacifique durant quelques années,

(2) ils sont distribués d'une façon assez dense pour supporter des pêches industrielles, et

(3) ils se déplacent largement entre les régions orientales et occidentales du Pacifique. Le stock exploité consiste surtout en âges IV et V. Le recrutement et la dispersion interviennent vers le mois de mars.

Le taux de capture à la longue ligne est le plus représentatif de la dimension du stock dans la zone de pêche. La force de classe d'âge est établie sur la composition en âge de la pêche.

Les statistiques de pêches étudiées des années 1949 à 1959 ont montré que la force de classe d'âge est le facteur déterminant les apports annuels. L'abondance du stock est plus importante que sa disponibilité pour que la pêche soit fructueuse dans le Pacifique du Nord-Ouest. Les facteurs de milieu de la phase de pré-exploitation doivent être pris en considération dans l'analyse des grandes fluctuations de la dimension du stock disponible par classe d'âge.

Comme la dimension du stock est le facteur qui commande le volume de la pêche de thon germon dans le Pacifique du Nord-Ouest, la détermination du recrutement est essentielle pour que la prédiction soit bonne. Bien que les renseignements que nous pouvons actuellement réunir sur les stades précédents ne soient pas assez sûrs pour permettre une prévision des dimensions de stocks à venir, le progrès méthodologique rendra cette prédiction plus aisée dans l'avenir.

ESTRUCTURA DE LA POBLACION DE ALBACORA Y FLUCTUACIONES DE SU PESCA EN ZONAS DEL NORTE DEL PACIFICO

Extracto

Estudios basados en diarios de pesca, muestreo de ejemplares, experimentos de marcado y datos análogos relativos a la albacora del norte del Pacífico revelan:

La albacora desova en la corriente ecuatorial del norte y pasa los pocos años de su fase inmadura en la corriente del norte del Pacífico; está distribuida con suficiente densidad para mantener la pesca industrial y realiza grandes emigraciones entre las partes oriental y occidental del Pacífico. La población explotada consiste principalmente en individuos de edad IV y V. El reclutamiento y la dispersión ocurren hacía marzo.

La proporción de capturas por anzuelo de palangre es la que mejor representa la cuantía de la población en una zona de pesca. La magnitud de la clase anual se ha estimado a partir de la composición por edad de la captura.

Las estadísticas de pesca para 1949-1959 indican que la magnitud de la clase anual es el factor que gobierna los desembarcos de cada año. La abundancia de la población es más importante que la disponibilidad para que la pesca tenga éxito en el noroeste del Pacífico. Los factores ambientales de la fase preexplotada tienen que ser tomados en consideración para analizar grandes fluctuaciones en la magnitud de las poblaciones disponibles por clases anuales.

Como la magnitud de las poblaciones es el factor que regula la pesca de albacora en el noroeste del Pacífico, la determinación del reclutamiento es esencial para hacer previsiones correctas. Aunque la información actual sobre los puntos anteriores no es lo bastante segura para hacer previsiones de las tallas subsiguientes de las poblaciones, la mejora de la metodología la hará más práctica en el futuro.

1 INTRODUCTION

Landings of the albacore, Germo germo (Lacépède), in the northwestern Pacific area have fluctuated remarkably from year to year. For instance, in the catch by Japanese pole-and-line boats, the variation coefficient reached 30 percent for the period 1949 through 1959. The catch in a most thriving year (1957) approached 50,000 tons, or one and a half times the average annual catch, while the catch in the worst year (1959) fell below 15,000 tons, or less than half the average catch. According to studies on albacore carried out by the author in the waters under discussion, changes in the stock size show uniformity over a wide geographical range nearly throughout the year. This seems to be a major factor controlling the annual catch.

Modernization of a fishery possibly means a planned production. Although the abundance cannot be regulated for the planned catch, it is still possible to some extent to introduce a planned production to the industry on the basis of predicted catch. The planning of the fisheries may be advanced when the prediction becomes reliable.

Most previous studies on fluctuation in the catch of albacore were based on examination of change in the availability. For this reason, study was concentrated on distribution pattern of stocks such as position and migratory route of fish, duration and season of fishing activities and depth of swimming layer. But little attention was given to the change in abundance itself. However the total albacore catch has fluctuated mainly because of abundance rather than of availability. Therefore, when studying catch fluctuations, abundance changes should also be investigated. The present report deals with the fluctuation in abundance of albacore in the Pacific north of the Equator, not only in the northwestern part exploited by Japanese boats but also in other important parts of the ocean.

2 COMPOSITION OF THE ALBACORE STOCKS IN THE NORTH PACIFIC AREAS

2.1 Relationship between the albacores in the North and the South Pacific areas

According to Suda et al (1959), fish are scarce in equatorial waters. Densely distributed zones extend far from the Equator, toward east and west between 25 and 40°N in the northern hemisphere and south of 10°S in the southern hemisphere.

Two groups of the albacore in the southern and the northern hemispheres differ from each other in several biological characteristics. Kurogane and Hiyama (1957) sampled specimens from three areas: 1) northwestern Pacific (35 to 40°N, 155 to 175°W), 2) western equatorial area (2°N to 7°S, 153°E to 161°W), and 3) southwestern Pacific (13 to 28°S, 153 to 158°E). They found remarkable morphological differences between fish from area (1) and those from the other two areas. Therefore, the fish in area (1) seem to belong to a homogeneous stock differing from stocks in the other areas. Otsu and Hansen (1961), also assume that two stocks of albacores in the southern and the northern hemisphere are distinctly separated since the spawning seasons in those two areas are completely different.

These two stocks also differ in body size. Figs. 1 and 2 show the body-length compositions of albacore caught in the North Pacific (Suda 1956) and the South Pacific (Kamimura and Honma 1956). In both figures, Panel A represents the composition of spawning fish and Panel B that of immature fish (see section 2.2 for the reasons segregating the spawning fish from the immature). The largest southern hemisphere fish rarely exceed 110 cm and are about 10 cm smaller than those from the north.

The smallest spawners in the South Pacific also are supposed to be shorter by about 10 cm in body length than those in the North Pacific. Such discrepancy of body length in the northern and the southern hemispheres indicates a geographical difference in growth rate and maturing size.

Fig. 4 shows latitudinal change of hooking-rate between 150° and 170°E. The distribution density of the albacore stocks, depending upon the current system, decreases by about one-fifth or one-sixth from the North Pacific Current to the North Equatorial Current and by a similar portion from the North Equatorial Current to the Equatorial Counter Current (Nakamura and Yamanaka 1959; Suda et al 1959). The stock size is smallest in the Equatorial Counter Current, possibly a boundary region between the northern and southern Pacific stocks. South of the Equatorial Counter Current, the stock size increases again with the latitude: the density becomes several times greater from the northern part of the South Pacific Current which is north of supposed convergence on 10°S (Yamanaka 1956) to another area south of the Current.

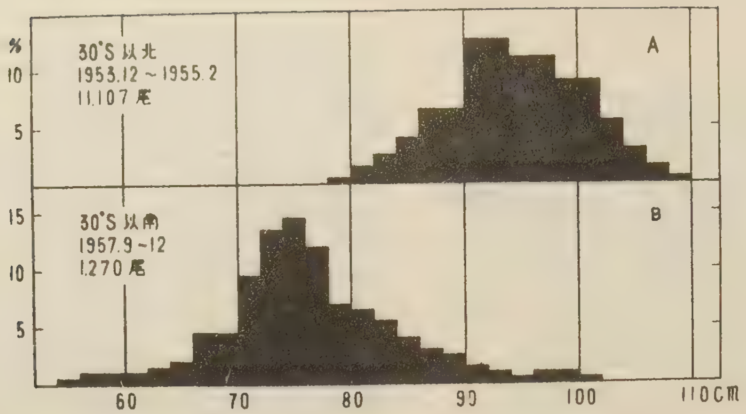


Fig. 1 Body-length composition of albacore in the southern Pacific

A Spawning fish
North of 30°S
December 1953 -
February 1955
11,107 individuals

B Immature fish
South of 30°S
September -
December 1957
1,270 individuals

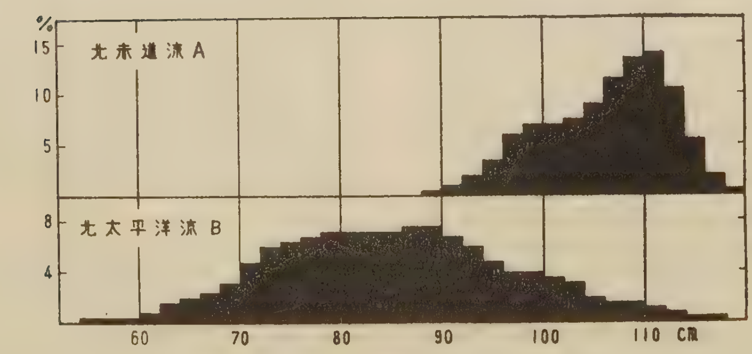


Fig. 2 Body-length composition of albacore in the northern Pacific

A Spawning fish
in North Equatorial
Current

B Immature fish
in the North Pacific
Current

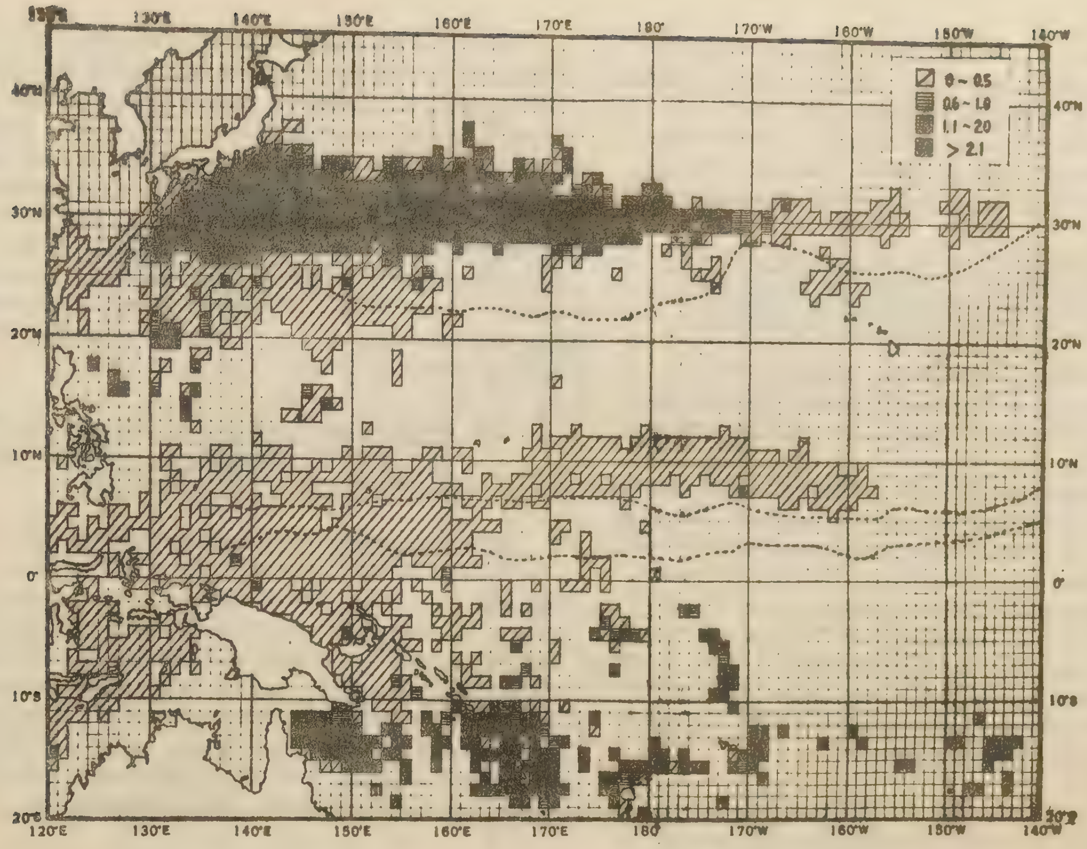

120°E
130°E
140°E
150°E
160°E
170°E
180°
170°W
160°W
150°W
140°W
40°N
30°N
20°N
10°N
0°
10°S
20°S
0 ~ 0.5
0.6 ~ 1.0
1.1 ~ 2.0
> 2.1

Fig. 3 Distribution of the albacore in the western Pacific (as of February)

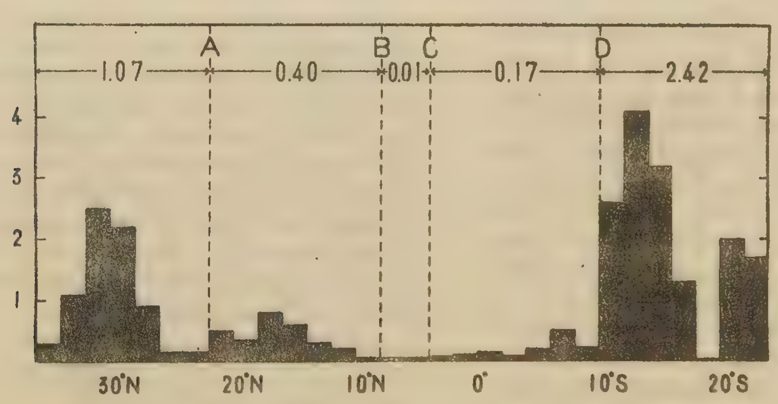


Fig. 4 Latitudinal change in the hooking-rate of the albacore in the western Pacific (150°-170°E, March)

A Boundary between the North Pacific Current and North Equatorial Current

B Boundary between North Equatorial Current and Equatorial Counter Current

C Boundary between Equatorial Counter Current and South Equatorial Current

D Convergence line on 10°S (Yamanaka 1956)

All the above information suggests that the albacore stocks in the North and the South Pacific areas differ in many biological features and hardly intermingle with each other. For this reason, the South Pacific stocks are not taken into consideration in the following discussion.

2.2 Relationship between feeding stock in North Pacific Current and spawning stock in North Equatorial Current

The three major fisheries north of the Equatorial Counter Current (Table I) are in the North Pacific Current and its continuations and the Kuroshio and California Currents (Fig. 5). Thus, an albacore stock dense enough to support commercial fisheries is found in an area between the Subtropical Convergence and the Polar Front, under an influence of the North Pacific Current. The stock size decreases rapidly in the North Equatorial Current south of the Subtropical Convergence (Figs. 1 to 4). Referring to this local change of distribution, Uda and Tokunaga (1937) said the Subtropical Convergence is the southern limit of albacore fishing grounds.

The fish in the North Equatorial Current differ in many points from those in the North Pacific Current and have a lower distribution density. Let us compare the length compositions of catch from these two currents. The composition of catch by Japanese fisheries has been shown in Fig. 2-B. Figs. 6 and 7 indicate the length frequencies of fish landed in the United States (Graham 1957), and Canada (Partlo 1955a). Albacore caught north of the Subtropical Convergence were mainly III-to-V age fish, being under 90 cm in body length (Nose et al 1957). On the other hand, albacore caught south of the Subtropical Convergence comprise the largest fish over 90 cm as shown in Fig. 2-A. Ueyanagi (1957) and Otsu and Uchida (1959a) inferred the biological minimum size of the female albacore in the middle and western parts of the North Pacific to be 90 cm in body length, on the basis of examination of ovary size. From their results, it may be stated that most of the fish in the North Equatorial Current are over 90 cm and sexually mature while most fish in the North Pacific Current are immature. Further, Ueyanagi (1957), pointing out that in the northwestern Pacific the fish with ripe ova occur only south of the Subtropical Convergence, assumed that albacore spawn over a wide area along the North Equatorial Current. He is dubious about Partlo's (1956) inference that nearly-mature albacore are caught in the northeast Pacific off Canada.

The above information reveals that the albacore population inhabit the North Pacific Subtropical Circulation and are segregated - as though by the Subtropical Convergence - into two general stocks: the spawning stock in the southern half of the Circulation (1) the North Equatorial Current stock and the immature stock in the northern half of the Circulation, and (2) the North Pacific Current stock, which is dense enough for commercial exploitation. The fact has an important bearing upon discussing interchange between them.

2.3 Relationship between albacore stocks in the eastern, central and western areas of the North Pacific Current

Both the stock of the immature fish in the North Pacific Current and the stock of the mature fish in the North Equatorial Current has a distribution area which is longitudinally limited, but extends latitudinally far across the Pacific. Therefore, it is necessary to discuss the stock structure, especially the intermingling of fish in the eastern and western areas, emphasizing the immature stock in the North Pacific Current, on which the fisheries are mainly dependent.

2.3.1 Structure of the albacore stock in the western area of the North Pacific Current

2.3.1.1 Review of previous work

At a symposium for causes of decrease of summer albacore catch, Sakai (1936) assumed the existence of virtually independent stocks in the western Pacific adjacent to Japan. According to him, they are: a northward migrant exploited by pole-and-line in the area 500 miles offshore, and two southward migrants exploited by longline in winter in the areas 1,000 and 1,700 miles offshore. These groups seem to migrate south to north to south but not west to east to west. The northward migrant in summer may probably move back southward along the same route as in winter, although this possibility has not yet been confirmed.

On the same occasion, Marukawa (1936) assumed two separated stocks, one around the Midway Islands and the other close to Japan. He suggested: that the fish exploited off Shikoku and Kyushu would spawn off Okinawa and Kyushu, and probably the Bonin Islands, as do the skipjacks, and would migrate as far north as off Boso Peninsula and Sanriku; the fish caught off the Midway Islands and Hawaii may belong to

Table I

Comparison among three major types of Albacore fisheries in the North Pacific

Item	Japanese pole-and-line	Trolling, pole-and-line of U. S. A. and Canada	Japanese longline
Fishing ground	28-40°N, 135-165°E	East of 20-60°N, 100°W	28-40°N, 130°E-175°W
Fishing season	3 months from mid-April	3 months from July	6 months from late October
Age groups	III, IV, V	III, IV*	III, IV, V, VI
Ratio of IV- and V-age groups	90%	50%*	60%
Average annual catch (1954-1958)	30, 300 tons	18, 200 tons**	15, 900 tons

* Brock 1943; Partlo 1955

** Anderson _et al_ 1953; Van Campen 1960

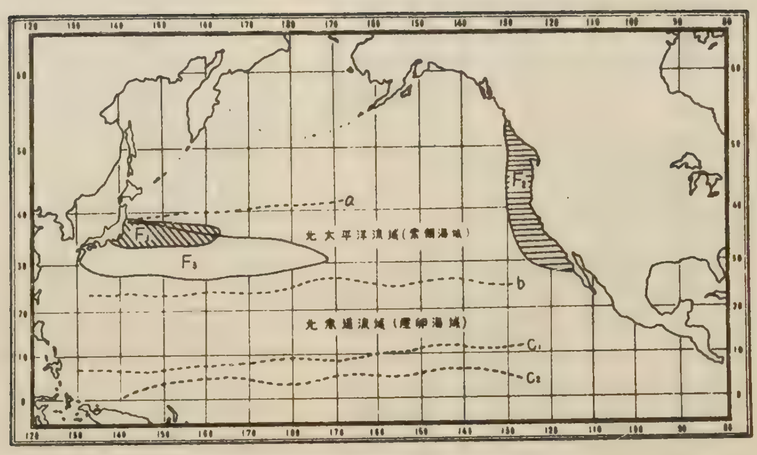


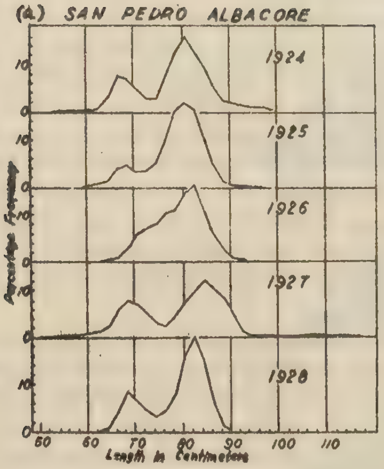
Fig. 5 Relationship between oceanographic structure of the northern Pacific and fishing ground of albacores

a Polar front, b Subtropical Convergence Line,
c Boundaries of the Equatorial Counter Current

F_1 Fishing ground of Japanese pole-and-line

F_2 Fishing ground of pole-and-line and trolling off North America

F_3 Fishing ground of Japanese long-line



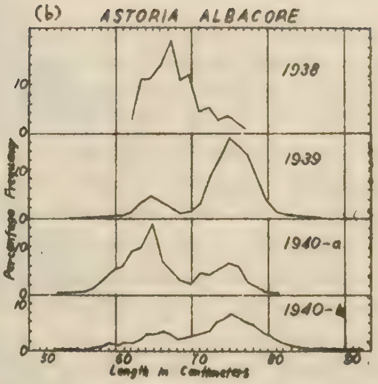


Fig. 6a Body-length composition of albacore, San Pedro, U.S.A., 1924-28 (Graham 1957)

Fig. 6b Body-length composition of albacore, Astoria, U.S.A., 1934-40 (Graham 1957)

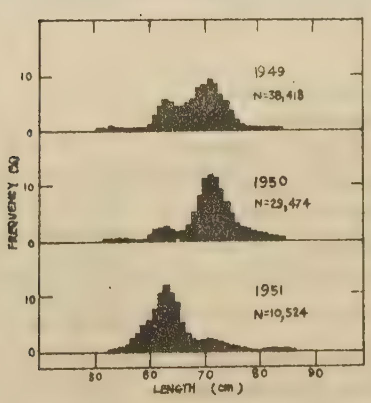


Fig. 7 Body-length composition of albacore, Canada, 1949-51 (Partlo 1955a)

the same stock off California; the eastern stock may not move toward the Japanese Islands since there is no fishing ground between the distribution ranges of the above two stocks.

Uda and Tokunaga (1937) supported coastal and offshore stocks on the basis of surveys on the albacore catch over a year from autumn 1935 to the following summer. The coastal stock, I, consists of group A_0 including the large, medium and small fish staying in coastal waters, and group B_1, mainly small fish with medium ones, immigrating from offshore. The offshore stock, II, which appears at 1,000 to 2,000 miles off Japan, comprises group B_0, large, medium and small fish, staying offshore, and group A_1, mainly medium fish with the small ones, immigrating from coastal waters. In coastal waters, fishing intensity has been so high that group A_0, especially the large fish, decreased remarkably. In offshore waters fishing intensity is not so high as to deplete the stock size there remarkably, even though both B_0 and B_1 seem to be on the decrease. Soon, the I and II stocks may not intermingle but some individuals of each stock would move into the distribution range of the other stock over a long period of four or five years or more.

Uda differed from Marukawa in positively proposing presence of the intermingling groups A_1 and B_1.

Aikawa (1948), while proposing two stocks and a mixture of them as well, refuted the presence of A_0 and B_0 assumed by Uda. Instead he inferred that the coastal and offshore stocks were separate, depending on ecological discrimination caused by difference of age. The albacore off North America may be separate from those off Japan.

The above authors, except Aikawa, assumed the presence of two or three entirely independent or partly independent albacore stocks, although the opinions differ on the degree of intimacy between stocks, possibly because of interpretations: 1) there are two or more separated distribution areas; 2) the fluctuation in catch differs from area to area.

However, as the present author doubts the reliability of the above interpretations as a ground of proposing separated stocks, he wishes to discuss these problems on the basis of up-to-date information.

2.3.1.2 Identification of a stock or stocks

Geographical changes of longline hooking-rate indicates that the fish are distributed in narrow zones along latitudes (Suda, Tatsuki and Uto 1959) (Fig. 3). Although the abundance varies even within the zone, such geographical heterogeneity of the hooking rate that disappears within a short period possibly merely reflects the effects of minor oceanographical conditions, but not the discontinuous distribution or presence of several independent stocks.

Geographical changes of fishing season and age composition of catch also support the presence of independent stocks (Fig. 8). The center of the albacore distribution in the North Pacific Current moves southwestward in autumn and winter, and northeastward in spring and summer. Therefore, the highly populated area changes from month to month. In addition, the size of fish exploited in the longline season decreases month after month because V-age fish and older emigrate for spawning while III-age fish immigrate into the fishing ground (see section 2.4). Thus, the geographical differences of fishing season and size composition of catch may suggest apparent discontinuity of the population affected by seasonal changes of distribution but do not seem to reflect the presence of independent stocks.

2.3.1.3 Area change of annual fluctuation in catch

In the years around 1952 the presence of two or more stocks was assumed partly because, in those days, the albacore catch decreased in the waters adjacent to Japan while it increased offshore. However, when the longlining ground from 140°E to 180°E is divided by 10° of longitude, highly positive correlations are found between the hooking-rates in the eastern and the western areas (Table II). In addition, size composition of catch indicates a common fluctuation over these areas because a dominant age group often occurs in more than one area (Table III). Furthermore, the quantitative fluctuation in longline catch resembles that of pole-and-line. Catch amount by pole-and-line is highly correlated with that by longline operated a half year later with the correlation coefficient between these catches reaching 0.92 (d. f. = 6).

Morphological comparison by Kurogane and Hiyama (1957) also indicates that: i) albacores

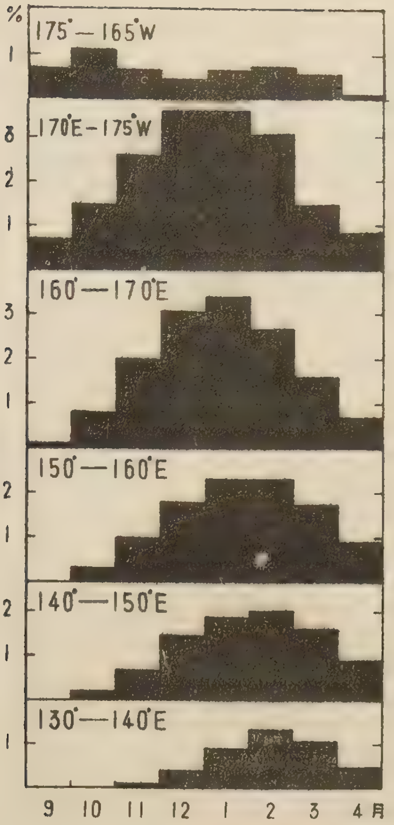


Fig. 8 Seasonal change of albacore stocks exploited by longline

Table II

Coefficients of relationships between hooking-rates in areas of 10° of longitude in the North Pacific Current Area, 1949-1959 (D.F. =9)

	140°E-150°E	150°E- 160°E	160°E-170°E	170°E-180°
140°E-150°E	----------	-----------	----------	---------
150°E-160°E	+0.81	-----------	----------	---------
160°E-170°E	+0.78	+0.81	----------	---------
170°E-180°E	+0.77	+0.80	+0.95	----------

Table III

Dominant age groups of Albacore in the longline fishing season of the Northwest Pacific by areas of 10 degrees of longitude

Year	1949				1950				1951				1952				1953				1954				1955				1956				1957				1958				1959			
Area	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7	4	5	6	7
II-age																																												
III-age									d				d				D				D	D	D		D	d	d		d		d		d							D	d			
IV-age	D		d		D		D	d	D				D	D	D	d					d		d	d	d	D	D	D	D	D	D	D	D	D	D	D	D	D	D	d	D	D	D	D
V-age		D	D	D	d	D		D	d	D	D	D			d	D	d	D	D	D				D										d		d			d					d
VI-age						d				d								d																										
VII-age																																												

Area 4: between 140°E and 150°E
Area 5: " 150°E " 160°E
Area 5: " 160°E " 170°
Area 7: " 170°E " 180°

D: The most dominant age group

d: Age groups next to the most dominant and constituting more than 20% of the annual catch in each area.

caught by pole-and-line in the northwestern Pacific are segregated only by two or three morphological characters out of 18 from the longline fish in the high sea (155°E to 175°W), and: ii) the differences between these two stocks are much lower than the differences between the stocks in the northern and the southern hemispheres observed by the same authors (1957) (see section 2.1).

The above evidence renders it difficult to conclude that more than one stock of albacore exist in the western part of the North Pacific Current where Japanese boats operate. Since changes in environmental condition, if any, would take place only gradually within the Current, the western stock may easily intermingle with the eastern stock.

2.3.2 Relationship between albacores in the northwestern Pacific and the waters off North America

Valuable evidence on this problem accrued from tagging experiments conducted in the North Pacific Current area, particularly in the i) central part north of Hawaii (Otsu 1960); ii) eastern part off North America (Bluent 1954; Ganssle and Clemens 1953; Wilson 1953); iii) western part adjacent to Japan. A number of fish tagged in areas i) and ii) were recovered in the central and western areas while some went across from area i) to the waters along North America. This indicates that albacore move over a wide latitudinal range (Figs. 9 and 10). As shown in Table IV, there is a high correlation between season and geographical position of recovery. The fish are recovered in the western area during November through June, and in the eastern area during July through October. This correlation is explained from an assumption of the east and the westward movement of the fish as shown by arrows in Table IV.

To verify and advance the above assumption further, one may trace up fishing situations in the western and the eastern areas below:

1) West of 175°W, the stock usually increases its abundance and moves westward with progress of time from September till the following February (Fig. 8). When pole-and-line fishing begins in April in the area, the fish start returning east as shown by the tagging recovery (Fig. 10) and disappear from the area by early July.
2) In the eastern waters off North America the fishing season which lasts from June through November with the peak in August (Partlo 1955a; Clemens 1955; Brock 1943) occurs six months after that in the northwestern area near Japan. In other words, the albacores seem to spend six months crossing the Pacific back and forth.
3) In fact, three albacores tagged off North America were recovered in the central and the western Pacific six months later (Bluent 1954; Wilson 1953).
4) Therefore, it is feasible to assert that albacore migrate along latitudinal lines, concentrating in the western part of the North Pacific Current for a half-year around February and in the eastern part of the Current for the other half-year around August. However, the length composition (Table I) suggests that only a portion of the albacore stock is exploited by the fisheries of United States and Canada. Large and medium fish especially tend to stay out of the fishing ground along North America. On the other hand, most small fish remain behind larger fish entering the fishing ground near Japan during winter. Otsu and Uchida (1961) also maintain a similar hypothesis. Such migration of small fish has to be noted in association with a fact that the recruitment into the Japanese fishing ground is completed at the beginning of IV-age.

On the other hand, Godsil (1948), pointing out morphological differences between the albacores caught near Japan and the United States, emphasized the need of sampling a larger number of specimens to confirm his hypotheses:

1) Albacores near Japan may not intermingle with those along the United States.
2) Albacores around Hawaii are related more closely with those around Japan than with those along the United States.

Except Godsil, all the recent workers refute the presence of two or more independent albacore stocks in the North Pacific Current. At present, therefore, it is reasonable to assert that the Current is the habitat of a single stock of immature feeding albacores. Although only little evidence was obtained for the spawning

Table IV

Tagging recovery of Albacore in the North Pacific Current Area
(After Otsu 1960; Suda 1960; and Howard 1960)

Tagging area	Number of fish tagged	Recovering area	Number of fish recovered					
			1st year		2nd year		3rd year	
			Jul.-Oct.	Nov.-Jun.	Jul.-Oct.	Nov.-Jun.	Jul.-Oct.	Nov.-Jun.
Eastern part (off U.S.A. and Canada)	?	Eastern part	*(30)		2			
		Western part		7		3		
"	?	Eastern part		*			3	
		Western part				1		1
Central part (north of Hawaii)	308	Eastern part	*		2			
		Western part		1		2		1
Western part (off Japan)	1,113	Eastern part						
		Western part		*(8)				1

* Releasing month

The figures in parentheses represent the number of fish recaptured with the season when the release was carried out.

The dotted line indicates migratory coverage analogized from recoveries traced with the solid lines.

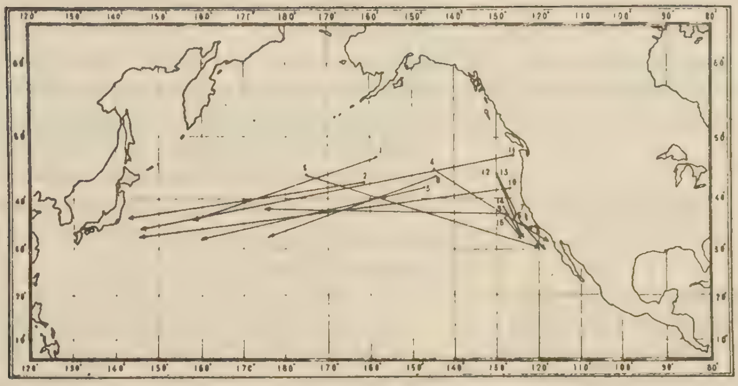


Fig. 9 Recovery of the albacores tagged by POFI (Otsu 1960)

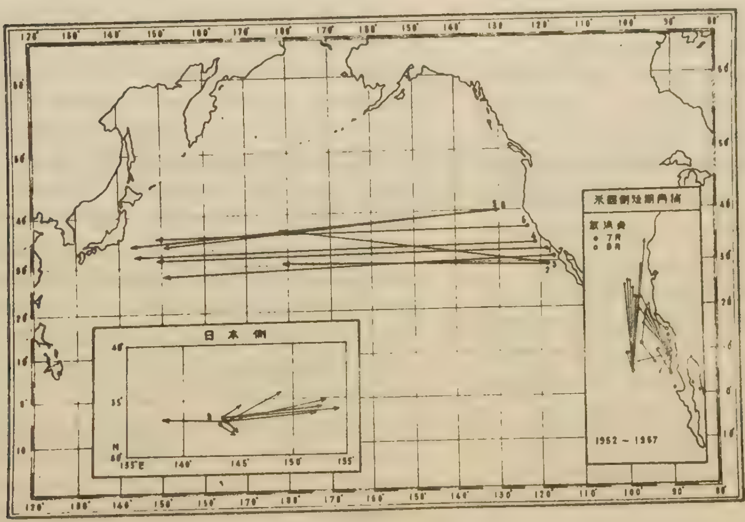


Fig. 10 Recovery of the albacore tagged by California Fish and Game (Howard 1960), and Nankai Regional Fisheries Research Laboratory.

Numerals denote the number of fish recovered long after they were tagged.

fish in the North Equatorial Current, they may also belong to another single stock since no oceanographic barrier has been found which prevents the east and the westward movement of the fish. Application of the term subpopulation to the North Pacific Current stock in relation with another in the North Equatorial Current is reserved for the time being.

2.4 Recruitment and dispersion in the northwestern Pacific

In describing here the formation of the albacore stock available to northwestern Pacific Japanese fisheries, the author wishes to elucidate: i) a season when the young fish are recruited, ii) age composition of the recruitment, and iii) effect of the recruitment upon catch.

In the northwestern Pacific, Japanese fishermen catch the albacore with pole-and-line in spring and longline in autumn and winter. The catches by these two fisheries are correlated as seen in section 2.3.1.

If the index of stock size (see section 3.2) in the pole-and-line fishing ground (L_n) is compared with that in the longline fishing ground ($\underline{S}_n$) a half-year later, the correlation coefficient (P_1) after 1952 reaches 0.92 (Fig. 11-a). But the index of stock size for pole-and-line (L_n+1) is not highly correlated (P_2 = 0.42) with that for longline ($\bar{S}_n$) half a year earlier (Fig. 11-b). The above correlations suggest that many members of the stock exploited in a pole-and-line season are common with the stock exploited by longline a half-year later but few of them are common with the one exploited by longline a half-year earlier. Since the pole-and-line fishing season lasts from May to July and the longline from October to March, the two types of fishing operated before or after March are not so highly correlated with one another (P_2 in Fig. 12-b) as are those before or after September (P_1 in Fig. 12-a). Thus it is possible to assume that the available stocks interchange about March. Younger members immigrate into the fishing ground and older members emigrate from it.

Monthly stock sizes in the longline season are correlated with stock sizes in the ensuing season. (Table V). Age composition of the longline catch is tabulated for each month (Table VI). Tables V and VI reveal that with progress of time in one longline season the stock size available in that season becomes more and more correlated with the one in the next season, and the III-age and younger fish increase in number, in place of large fish. The above evidence makes it reasonable: 1) to support the foregoing proposition about the month (March) around which the young and the older fish probably interchange with each other, 2) to interpret that on completion of recruitment the composition does not vary remarkably until the following March, 3) to regard, therefore, a year ending in March as one fishing season for albacore in the northwestern Pacific.

The increase of the stock size is remarkable in a stage from later III-age to early IV-age, and the decrease, in another stage from later V-age to early VI-age (Table VII). This indicates that the major recruitment are III- to IV-age fish. During the following two years, IV- and V-age fish comprise the major portion of the available stock. The older fish, VI-age, commence to leave the fishing ground. The older fish appear in the North Equatorial Current and may spawn in a short period around May and June (Suda 1954) (Fig. 12).

The recruitment of the young fish into the available stock should be distinguished from another recruitment of the young fish from the spawning area (North Equatorial Current) to the feeding area (North Pacific Current). Since the albacore spawn in the North Equatorial Current, one may naturally expect the young fish to come from that area. But the detailed process of that recruitment is not yet known. Therefore, it is not feasible to infer that the fish move from the North Equatorial Current to the North Pacific Current in the early IV-age by mere analogy from the recruitment in the North Pacific Current described above. Instead, it is highly probable that fish younger than IV-age immigrate somewhere outside the fishing ground in the North Pacific Current and stay there till they reach IV-age. In this connection, information should be accumulated for distribution of I- to III-age fish. According to present data, the geographical distribution of the fish in different stages of life history is assumed to be as in Fig. 13. The dotted lines denote the unknown process and the double lines the process to be followed by a majority of individual fish.

Table V

Relationships between abundances of Albacore by month in longline season in n-th year and total abundances of Albacore in pole-and-line and longline season in n+1-th year

Month	Oct	Nov	Dec	Jan	Feb	Mar
Coefficient of correlation between monthly index-$\bar{S}$ in n-th year and index-L in n+1-th year, 1951-1959 (D.F.=6)	-0.43	-0.71	+0.02	+0.32	+0.45	+0.50
Coefficient of correlation between monthly index-$\bar{S}$ in n-th year and index-$\bar{S}$ in n+1-th year, 1949-1959 (D.F.=8)	-0.21	-0.16	+0.05	+0.40	+0.59	+0.57

Table VI

Monthly age composition in percentage of Albacore caught by longline in the Northwest Pacific

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
III-age and younger	0	7	7	11	15	57
IV- and V-age fishes	64	77	75	70	69	36
VI-age and older	36	16	18	18	16	7

Table VII-a

Average age composition (per mill) of Albacore catch from the Northwest Pacific

	II-age	III-age	IV-age	V-age	VI-age	VII-age
Pole-and-line catch (1951-1959)	5	100	569	310	7	0
Longline catch (1949-1959)	10	137	385	345	92	31

Table VII-b

Differences of permillage between successive age groups of Albacore as in Table VII-a

	II-age -III-age	III-age -IV-age	IV-age -V-age	V-age -VI-age	VI-age -VII-age
Pole-and-line catch (1951-1959)	+95	+469	-259	-303	-7
Longline catch (1949-1959)	+127	+248	-40	-253	-61

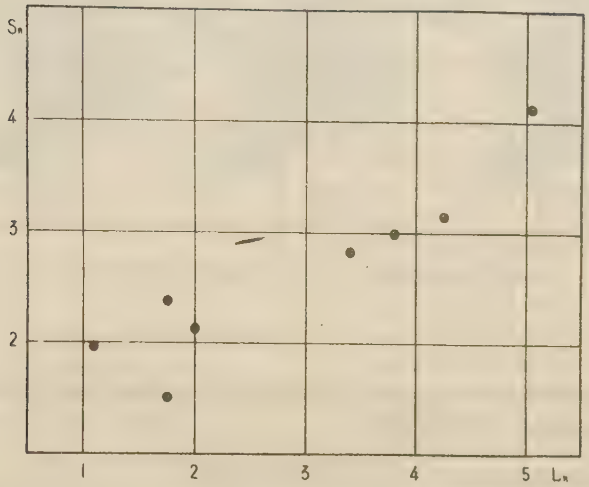


Fig. 11a Correlation between indices of stock sizes exploited by pole-and-line and by longline in a half-year later (ρ_1 = 0.92)

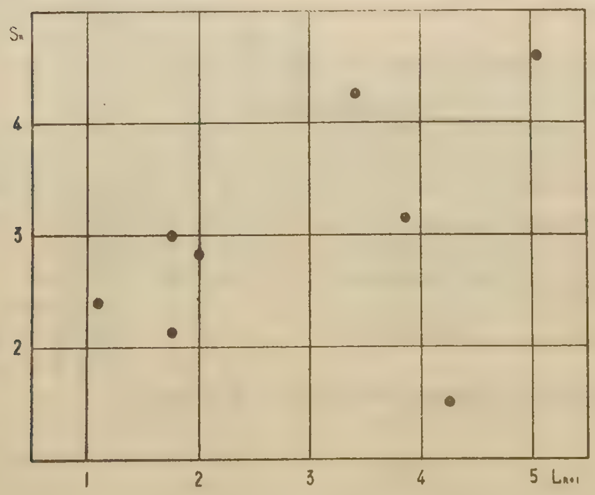


Fig. 11b Correlation between indices of stock sizes exploited by pole-and-line and by longline in a half-year before (ρ_2 = 0.42)

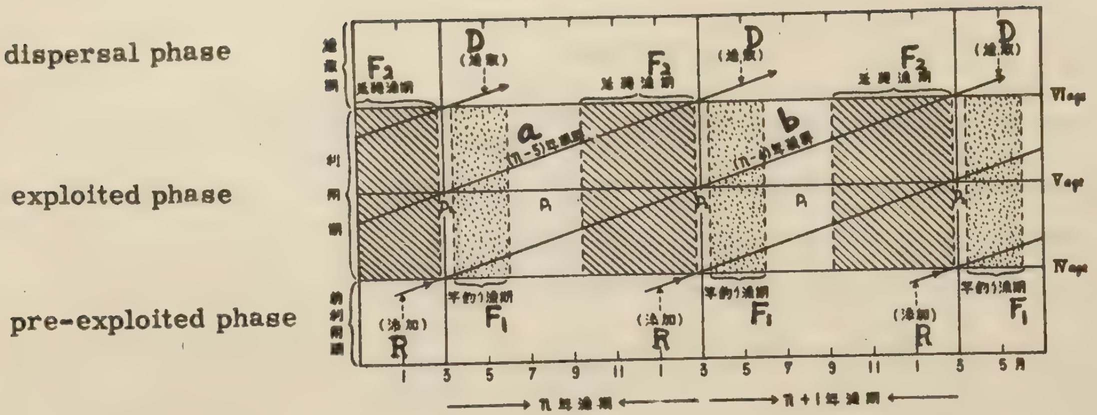

dispersal phase
exploited phase
pre-exploited phase
F2
D
F1
R
a
b
(n-5)
(n-4)
VI age
V age
IV age
1
3
5
7
9
11

Fig. 12 Schematic showing of formation of the exploitable stock in the northwestern Pacific

R recruitment D dispersion

F_1 fishing season of pole-and-line F_2 fishing season of longline

a (n-5)th year-class b (n-4)th year-class

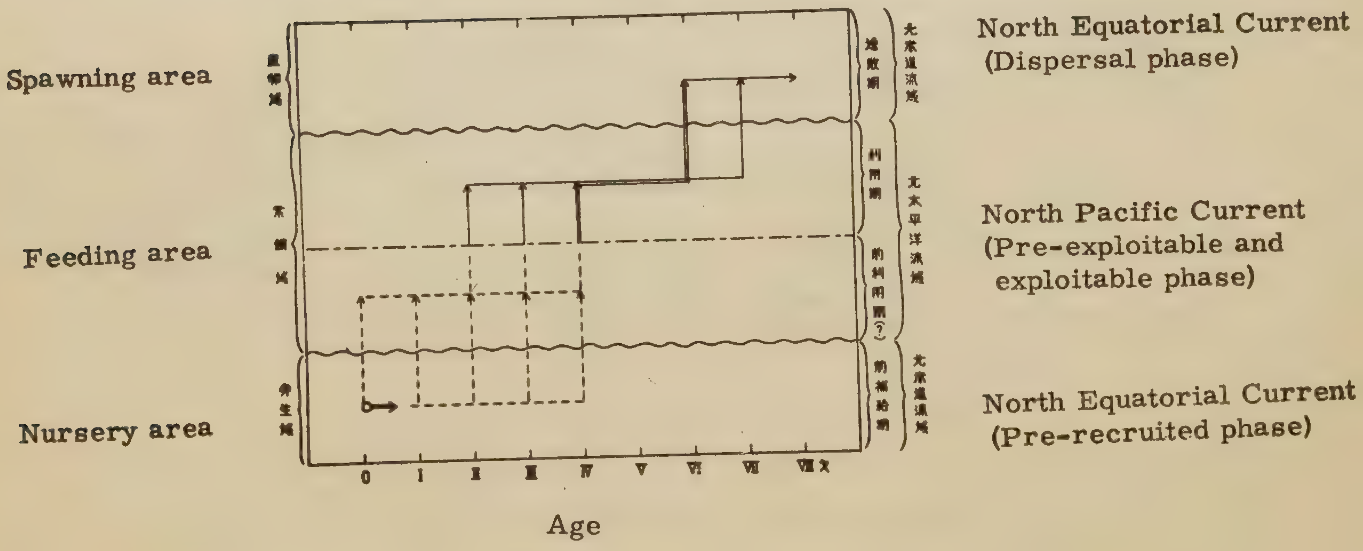

Spawning area
Feeding area
Nursery area
North Equatorial Current
(Dispersal phase)
North Pacific Current
(Pre-exploitable and exploitable phase)
North Equatorial Current
(Pre-recruited phase)
0
1
II
III
IV
V
VI
VII
VIII
Age

Fig. 13 Geographical positions of albacore stock in different stages of life history

3 AVAILABLE STOCK SIZE IN THE NORTHWESTERN PACIFIC

3.1 Source of data

In the northwestern Pacific the stock size of albacore may be represented by catch statistics of Japanese pole-and-line and longline fisheries. To estimate stock size from catch statistics, the data should cover the whole distribution range of the stock and as many age groups as possible. Let us consider to what extent the data from commercial catches satisfy these conditions.

3.1.1 Geographical coverage of data

Although the distribution range of the albacore extends over the North Pacific Current area, the stock mainly inhabits the western part in one season and the eastern part in the other. Therefore, an appropriate survey of commercial fisheries, especially longline fisheries, may provide sufficient information on the stock.

During winter, the major portion of the stock is distributed in the longline fishing ground between 130° E and 150° W with most of the boats frequenting the area from 130° E and 170° W (Suda, Tatsuki and Uto 1959). During the longline season the fish are accumulated in the western part of the North Pacific Current through the following process: Fig. 14 indicates monthly change of relative stock sizes of the albacore west of 170° W. In September when the fishing off North America begins off season, the fish begin to move westward. Stock size in western waters reaches its peak and becomes nearly constant for three months from December. From the westward movement of the distribution center shown in Fig. 8 it is inferable that almost all the fish from the east cross over the international dateline in December and move further westward in January and February until mid-February or March. In April the fish begin to migrate northeastward. With a rapid decrease of the hooking rate in March, the longline is replaced by the pole-and-line for the albacore by April. Thus, data on the longline catch from December through February in the area between 130° E and the dateline can provide information on the available stock size of recruited IV-age and older groups in the North Pacific Current.

Pole-and-line fishing ground located between 140° and 160° E is narrower than the one for longline. An inference based on expansion of the longline fishing ground in March suggests that a portion of the stock still remains east of 160° E even in seasons when the distribution range has moved most westerly. Therefore, although the major portion of the albacore stock is distributed in the pole-and-line area, this fishery may not cover the stock as entirely as the longline.

3.1.2 Adequacy of age group data

As shown in Table VII, the pole-and-line catches have fewer age groups than the longline. This fact, plus information from Table VIII indicates: i) the longline catches comprise six groups between II- and VII-age, ranging from 50 to 120 cm in body length; the pole-and-line catches have three groups from III- to V-age, 60 to 95 cm in body length, but hardly any II-age and younger or VI-age and older; ii) the age composition of both catches fluctuates from year to year, particularly in the pole-and-line catch; while all six age groups appear in the longline catch, only two groups, IV- and V-age, were caught by pole-and-line during the seven years from 1951.

The above facts justify basing the present study mainly on information from the longline catch.

3.2 Expression of stock size

3.2.1 Stock size available for longline

The amount of fishing effort cannot be evenly distributed in the longline fishing ground, which extends more than 3,000 miles from east to west. Therefore, the fishing ground is divided into five sub-areas in calculating the catch per unit effort, by means of the hooking rate, the number of fish caught per 100 hooks. Total and average indices (S and $\bar{S}$) of stock sizes in the fishing ground in a year are calculated by Suda (1958b) as:

$$S = \sum_{i} \sum_{j} X_{ij} \quad \text{and} \quad \bar{S} = \frac{1}{ij} \sum_{j} \sum_{i} X_{ij} \quad \ldots\ldots\ldots\ldots (1)$$

where i and j denote i-th subseason and j-th sub-area, respectively. Despite the longline season lasting from October to March, the data from December through February suffice for calculating the stock size (see section 3.1.1). The season is divided into the three months. The east of the dateline being excluded for the reason in section 3.1.1, the western area is divided into five sub-areas by 10° of longitude.

Table VIII

Coefficient of variation in the proportion (per mill) of each age group in the commercial catch from the Northwest Pacific

	II-age	III-age	IV-age	V-age	VI-age	Older
Pole-and-line catch (1951-1959)	146	103	37	70	184	
Longline catch (1949-1959)	79	76	47	54	44	63

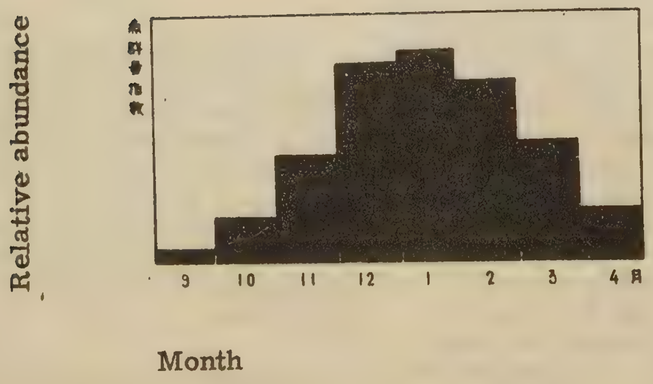


Fig. 14 Monthly change of the relative stock size of the albacore in the sea west of the dateline.

Values of $\bar{S}$[1] are shown in Table IX.

3.2.2 Stock size available for pole-and-line

In comparison with longliners, pole-and-line fishermen operate in a relatively narrow area as shown in Table I, possibly due to a limit of carrying live bait aboard; but as they operate for the fish swimming near the surface, they can find out distribution of fish more easily and their simpler gear enables them to move much more swiftly from place to place. Therefore, concentration of boats within a fishing ground seems to be more attributable to preference taken by fishermen than to partial information about fish distribution or to poor manoeuverability of boats. These facts make it almost safe to use the total catch as an index to the stock size available for pole-and-line, if fishing effort is constant for the period under study. However, as fishing effort expressed by standardized number of trip has been on the increase recently with the amount of effort around 1957 exceeding that of 1951 by over 125 percent, the stock size is indicated here by catch per unit effort. In future, it is probable that change will take place in expansion of fishing ground and that bias distribution of boats will affect the total catch. In that event, the stock size should be represented by catch per unit effort for each sub-area and sub-season, with the amount of effort most reasonably estimated by the number of poles and duration of every operation.

Through the above procedures, each stock size available for longline and pole-and-line is respectively calculated as an index which is correlated with each other as seen in section 2.3, if not confirmatively but noteworthily for examining reliability of these measures.

3.2.3 Size of available stock by year class

The above two stock sizes are measures of the stock including all the age groups. For examining change of stock in detail, the stock size has to be estimated by age or by year-class. The available stock size by year-class, P_a, is calculated by the following formula:

$$P_a = S'_{a.4} + S'_{a.5} \quad \dots\dots\dots\dots\dots\dots (2)$$

$$S'_{a.4} = \sum_i \sum_j (r_{a+4.4})_{ij} (X_{a+4})_{ij}$$

$$S'_{a.5} = \sum_i \sum_j (r_{a+5.5})_{ij} (X_{a+5})_{ij}$$

where a is the year when the class occurred.

$(r_{a+4.4})_{ij}$: ratio of IV-age fish to total catch in i-th month, j-th sub-area and $a+4$-th year

$(X_{a+4})_{ij}$: mean hooking-rate in i-th month, j-th sub-area and $a+4$-th year

$(r_{a+5.5})_{ij}$: ratio of V-age fish to total catch in i-th month, j-th sub-area, and $a+5$-th year

$(X_{a+5})_{ij}$: mean hooking-rate in i-th month, j-th sub-area , and $a+5$-th year

Since the recruitment is completed in IV-age, it may be just as feasible to express the year-class strength by stock size of IV-age fish. But the V-age fish dominates the longline catch in some years (Suda 1954). It is assumed that change of a dominant age group can be attributed to: i) a few fish being recruited to the available stock in V-age; ii) in some years stock size of IV-age fish is under-estimated because of change in availability, or iii) the dominating V-age fish happen to belong to a very strong year-class. If assumption i) or ii) is responsible for the change in dominant age group, the year-class strength should be represented not only by stock size in IV-age but also adjusted by that in V-age. For this reason, the stock size of each year-class has been estimated by formula (2).

In this formula, the age frequency was estimated from the length composition of catch. For the purpose, normal distribution curves are fitted to the body-length composition of catch in each fishing trip. On the basis of these normal curves, the catch is roughly divided into two or more groups and the mean length of each group is estimated. Remarkable modes are found in the distribution of these mean lengths. Taking these modes into account, Tanaka's (1956) method is applied for estimating the age composition of catch in each sub-area and sub-season.

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[1] The division of area and season for computing $\bar{S}$ slightly differ from those by Suda (1959).

Table IX

Annual changes in the amount of fishing effort and the catch per unit effort in the Northwest Pacific fishing grounds

	Pole-and-line fishing season				Longline fishing season			
Year	Total landings (10,000) (tons)	Number of standardized fishing trips	Index to number of trips based on 1951	Index -L (catch) (per) (unit) (effort)	Index-S (catch) (per) (unit) (effort)	Number of standardized trips in North Pacific & other areas	Ratio of number of trips in North Pacific	Index to total fishing effort based on 1951
1949					2.72			
1950					3.35			
1951	1.65	30,641	1.00	1.65	4.60	19,560	71	1.00
1952	4.33	26,363	0.86	5.04	4.25	22,716	77	1.26
1953	3.16	28,390	0.93	3.40	2.83	24,104	81	1.41
1954	2.19	33,684	1.10	1.99	2.12	22,534	71	1.15
1955	1.93	33,761	1.10	1.75	1.50	23,626	57	0.97
1956	4.08	29.453	0.96	4.25	3.15	25,955	45	0.84
1957	4.76	38,215	1.25	3.81	2.98	26,900	52	0.99
1958	2.21	39,042	1.27	1.74	2.38	25,795	50	0.93
1959	1.37	38,670	1.26	1.09	1.97	26,629	57	1.09

4 FLUCTUATION IN THE CATCH IN THE NORTHWESTERN PACIFIC

4.1 Importance of fluctuation in stock size

In Section 1.4, L and $\overline{S}$ are well correlated with each other to carry over a fishing situation of pole-and-line into the longline season occurring a half-year later.

It is also to be noted that the longline hooking-rates fluctuate in a similar trend among sub-areas of the fishing ground extending over 2,500 to 3,000 miles from east to west (Table II). Thus, the prosperity or adversity of albacore fishing takes place evenly over a wide area during a long period, offsetting local and temporal distribution differences. For this reason, it is believed that the primary factor determining the total amount of catch must be a change in the stock size, but cannot be a change in availability though the latter can affect local and temporal fishing conditions in Japanese albacore fisheries.

4.2 Recent fluctuation in stock size by age and year-class

Fig. 15 shows fluctuation in the stock size index, $\overline{S}$, for longline in the northwestern Pacific area during 1949 through 1959. From this figure it may be particularly noted; i) for a few years around 1951 and 1956 when the index reaches peaks, the stock size in the longline ground was relatively large; the adversity also continued for two or three years; ii) the stock size decreased remarkably in 1954 to 1955 and 1958 to 1959; in 1955 it was only one-third of that in 1951; the variation coefficient of the index, $\overline{S}$ is calculated at about 30 percent.

The annual trend of stock size for pole-and-line, L, closely resembled change of stock size for longline and had a greater variation; the variation coefficient of the index reached 45 percent.

The stock size by age for 1949 to 1959 is shown in Fig. 16. For a prosperous period from 1949 to 1952, IV- and V-age fish dominated alternatively from year to year, suggesting that a strong year-class occurred every two years. Although no strong year-class appeared in 1954 and 1955, the successful fishing in 1956 was brought forth by a strong year-class as IV-age, which again provided a good catch of V-age fish in 1957. Thus, year-class strength is highly related with success of fisheries.

Since the year class strength is found variable, the annual fluctuation in available stock size of each class is examined on the basis of the index, P_a indicated in Fig. 17 for 1945 to 1954 classes. Comparison of Fig. 17 with Fig. 15 reveals that annual fluctuation in P_a resembles the change of $\overline{S}$ four years later. Thus, the available stock size, $\overline{S}$, depends upon the strength of a year-class having occurred in four, or sometimes five, years before. A wider variation of P_a than that of $\overline{S}$ may be attributed to a possibility that different strengths of year-classes offset each other. Variation coefficient of P_a reached 45 percent or about 1.5 times as much as that of $\overline{S}$, 30 percent.

Now change of P_a is to be examined in association with other groups of data.

4.2.1 Relation between year class strength and its total catch

The number of individuals fished each year was calculated through the procedure shown in Table X. The total catch from 1950 class, for instance, is obtained by summing up catches of II-age fish in 1952, III-age in 1953, IV-age in 1954, and V-age in 1955. The number of VI-age and older fish was excluded from computation because they were scarce and not estimatable precisely for frequency. In Table XI, a linear relationship exists between pole-and-line catch of IV-age fish and $S'_{a.4}$ and between pole-and-line catch of IV- and V-age fish and $S'_{a.5}$. These correlations indicate that pole-and-line catch, the majority of the commercial landings, is proportional to the remaining stock to be exploited in the succeeding longline season. For these reasons, the indices $S'_{a.4}$ and $S'_{a.5}$ indicate not only stock size in longline fishing ground but also stock size prior to entering pole-and-line grounds. In other words, the stock size moving to longline ground is apparently determined before it is exploited there. Such characters of $S'_{a.4}$ and $S'_{a.5}$ are reflected in the index P_a, and the value of P_a may represent the year-class strength of the pre-exploited phase or more strictly at the time of being recruited into the northwestern Pacific area.

4.2.2 Comparison with stock of bigeye tuna

As mentioned above, each of the 1945 to 1948 classes was or was not dominant every two years. Reflecting this change of year-class

Table X

An example of age composition of Albacore catch by type of fishing

Year	Type of fishing	Total landings (tons)	Mean weight of fish (kg)	Number of catches (10,000)	Age composition (1/1000)					Number of fish in age group (10,000 of fish)				
					II	III	IV	V	VI	II	III	IV	V	VI
1952	Pole-and-line	43,335	8.74	490.6	14	283	393	294	14	6.9	140.4	194.9	145.8	6.9
1952	Longline	14,075	12,71	118.6	20	102	401	318	160	2.4	12.1	47.6	37.7	18.9
1953	Pole-and-line	31,605	10,54	299.9	-	56	486	458	-	-	16.8	145.8	137.4	-
1953	Longline	20,674	12.90	160.3	25	307	163	355	151	4.0	49.2	26.1	56.9	24.2

Table XI

Population size (Index-P_a) and the number of pole-and-line catches (Indices-A, -B and -C) of each year-class of Albacore in the Northwest Pacific

Index	1948	1949	1950	1951	1952	1953	1954
P_a	3.11	0.72	0.70	1.42	2.90	2.03	1.47
S_{a4}	1.75	0.38	0.56	1.01	1.83	1.45	0.97
S_{a5}	1.36	0.34	0.14	0.41	1.07	0.58	0.50
A	194.9	145.8	122.1	173.9	326.1	234.2	142.9
B	332.3	208.9	136.4	222.0	480.0	272.8	175.0
C	448.0	416.0	257.0	376.7	613.0	?	?

Index-P_a (=Index-S_{a4} + Index-S_{a5}): Index of the year-class size

Index-S_{a4}, Index-S_{a5}: See the equation (2)

Index-A: Number of fish of a given year-class caught as IV-age by pole-and-line (unit: 10,000)

Index-B: Number of fish of a given year-class caught as IV-age by pole-and-line (unit: 10,000)

Index C: Total number of fish of a given year-class which were caught throughout its life history (unit: 10,000)

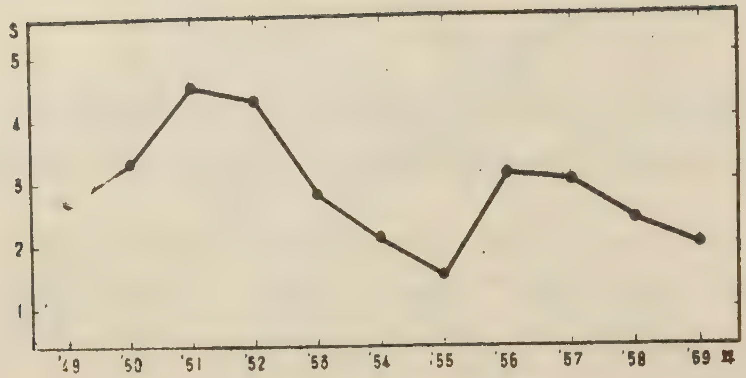

Fig. 15 Stock size index, $\overline{\underline{S}}$, of the albacore in the longline fishing ground in the northwestern Pacific, 1949-59.

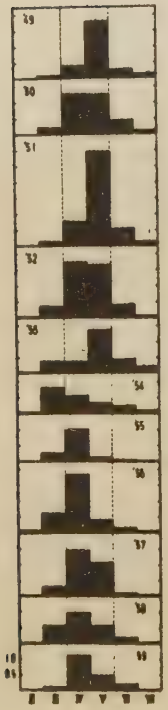

Fig. 16 Hooking-rate of albacore in different ages, in long-line fishing ground in the northwestern Pacific 1949-59.

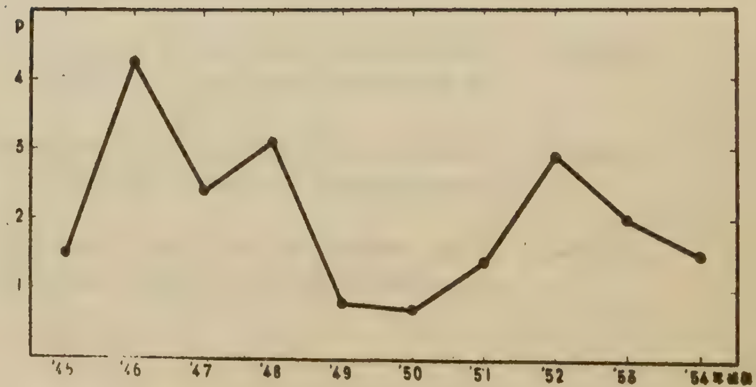

Fig. 17 Size of available stock by year-class of 1945-5

strength, IV- and V-age groups fluctuated every two years for 1949 to 1953 as in Fig. 16. A similar change of the year-class strength was found in the bigeye tuna in the period and area under discussion (Kamimura and Honma 1953; Nakamura et al 1953; Suda 1954). When $\underline{C}$ and $\underline{D}$ groups of the bigeye tuna in Fig. 18 are compared with IV- and V-age groups of the albacore, the fluctuations in stocks of both species resemble each other (Suda 1962). It may be asserted, therefore, that the above yearly change of stock occurs not only in the albacore but also in related species.

4.2.3 Year-class strength and environmental conditions in the spawning ground

The year-class strength, $\underline{P}_a$, is negatively correlated with mean body length of the class at II-age (Table XII). Since the II-age fish is the youngest member of the stock exploited in the North Pacific Current, its characters should most clearly reflect environmental conditions of the spawning area, the North Equatorial Current. It is probable that under these conditions the population size affects the growth of individual fish in the spawning area through competition.

4.2.4 Year-class strength and spawning stock size.

Although ratio of matured fish in each age group has not been clarified yet, the biological minimum size of female albacores is estimated at about 90 cm in body length (e.g., Ueyanagi 1954 and 1957). Since the major spawning season occurs in May and June, V-age fish (87 to 91 cm in mean body length) exploited by longline during November through February would spawn in the ensuing spring at VI-age. Therefore, the index of spawning stock size may be given by total catch of V-age and older fish landed by longline in a preceding year, though this value should be corrected in regard to ratio of matured fish in each age group in future. In Fig. 19 the correlation between the spawning stock size in a year and the stock size spawned in the year is not so clear.

The discussion in section 4 is summarized as follows:

1) The total abundance of available stock $\overline{\underline{S}}$ is mainly affected by the strength of component year-classes, $\underline{P}_a$.

2) The available year-class strength $\underline{P}_a$, fluctuates remarkably.

3) The index, $\underline{P}_a$, relates with the stock size in the pre-exploited phase. In other words the available stock size of each year-class is determined before the class immigrates into the fishing ground.

4) It is suggested that factors governing the year-class strength of the albacore may also affect the stock size of related species, and that environmental conditions of the spawning area play an important role in determining the stock sizes of tunas.

5 PREDICTABILITY OF FISHING CONDITIONS

This section deals with questions as to how much and by what means it is possible to predict fluctuation of fishing conditions discussed so far - pole-and-line catch $\underline{L}$, longline hooking-rate $\underline{S}$, and year-class recruitment $\underline{P}_a$. One of the keys to the prediction is direct information from a year-class stock that, once recruited to the fishing ground, stays within a whole fishing area over several seasons. The other is indirect information from other biological evidence of the year-class stock that may be related with the size of the year-class (e.g. Table XII).

5.1 Direct prediction from stock size carried over seasons

In the northwestern Pacific every year-class is recruited into the fishing ground and exploited as follows:

1) Among the recruitment into the exploitable stock only a minor portion comes from II- and III-age fish.

2) Major recruitment comes from a later stage of III- and early IV-age fish.

3) Major recruitment takes place during a short period around March.

4) The composition of the available stock is then determined and does not vary much until the ensuing March.

5) majority of catch consists of IV- and V-age fish, particularly the former caught by pole-and-line.

Table XII

Comparison between mean body length in II-age and population size (index-P) of each year-class

Year-class	1946	1947	1948	1949	1950	1951	1952	1953	1954
Mean body length of year-class in II-age	56.5	54.0	55.0	58.0	59.0	57.0	54.5	55.0	57.5
Index-P	4.26	2.43	3.11	0.72	0.70	1.42	2.90	2.03	1.47

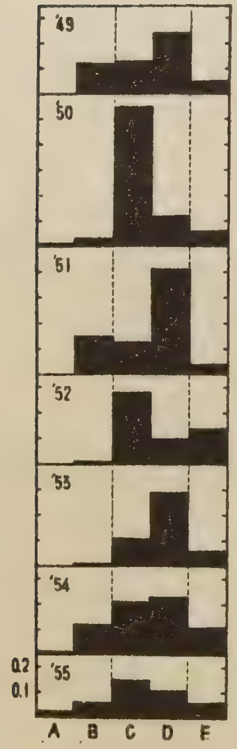

Fig. 18 Body-length composition of the bigeye in the north-western Pacific area (Suda et al 1959)

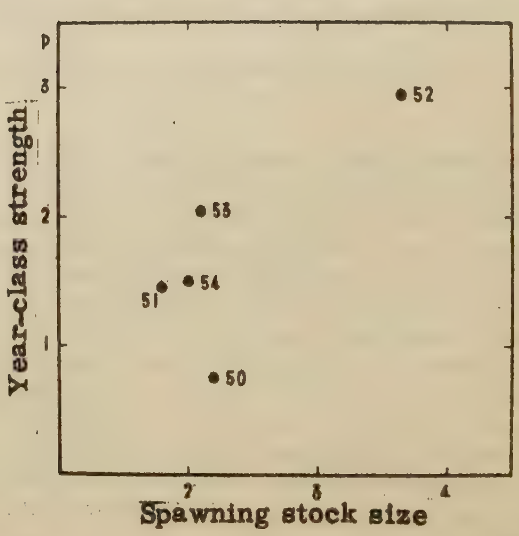

Fig. 19 Relationship between size of spawning stock and year-class strength produced by them

6) These procedures in which the major recruitment is exploited are schematically shown in Fig. 20;

7) Most fish older than V-age move out of the North Pacific Current into the North Equatorial Current for spawning.

As seen in Fig. 20 the size of a recruited stock to be carried over years within a whole fishing area is measurable at least in five periods of time, before and within the major exploitable phase. The recruitment procedures described above in passages 1) to 3) enable us to divide the pre-exploitable phase into two periods: i) a stage including II-age and late III-age before February toward the end of longline season, and ii) the remaining stage of III-age and early IV-age through March at the beginning of pole-and-line season. Subsequently, the major exploitable phase is divided into three more periods: iii) pole-and-line period in the northwestern Pacific, iv) trolling and pole-and-line period in the northeastern Pacific, v) longline period again in the northwestern Pacific.

The feasibility of prediction of the major exploitable stock size in the northwestern Pacific area from information obtained during these periods is discussed below.

5.1.1 Prediction from young stock size available in period i)

Abundance of young albacore at II- and III-age can be estimated to some extent from either pole-and-line catch or longline hooking rate. So far, however, the abundance has no significance for predicting the stock size in the major exploitable phase as shown in Table XIII, probably because the majority of these fish are still too far from the fishing ground to provide sufficient information. Success in the prediction from the stock size in period i), therefore, depends upon the possibility of conducting surveys on the stock size in the pre-exploitable phase, or according to Beverton (1951), pre-exploited phase, when fish enter the fishing ground but are yet not fully exploited. At present we know but little about ecology of fish in the pre-exploitable phase. Furthermore, it is not easy to establish with data the pre-exploitable phase of albacore in a strict sense of the term. For solving these questions, we have to examine two postulations:

1) young albacore are distributed between the northern limit of the longline fishing ground and the Polar Front (Suda *et al* 1959);

2) the stock exploited near the United States, as most of them are small in size, belong to the pre-exploitable phase for the Japanese fisheries (Otsu 1959; Suda 1958).

For examining the validity of the first postulation, greater encouragement should be given to secure and analyze information from such fishing that harvests small albacore, incidentally or otherwise. North of the albacore longline ground, for instance, a special longline called *yonawa* hauls up a number of small albacores along with its main catch, swordfish, *Xiphyas gladius* (Yamanaka 1958); in the northern part of the central Pacific, gill-net and trolling records show the catch of young albacore (Graham and Mann 1959; Graham 1957; Shomura and Otsu, 1956).

If the second postulation is valid, the stock size in the northeastern Pacific in a year should be related with $\underline{L}$ and $\underline{S}$, stock size in the northwestern Pacific, one or two years later. A low correlation coefficient found between United States landings and $\underline{L}$ or $\underline{S}$ for the years 1952 to 1959 (Table XIV) does not seem to verify the second postulation as far as these values are concerned. Yet we need not give up this postulation for the reason to be discussed in 5.1.4. Extensive tagging experiments will provide valuable information for solving this problem.

If the majority of young stock have no pre-exploitable phase at all and directly enter the fishing ground from somewhere other than the North Pacific area, it will be difficult to predict the available stock size through the abundance in period i).

5.1.2 Prediction from late III- and early IV-age stocks in period ii)

Since the fish recruited to the fishing area in period ii) still do not represent the major recruitment, prediction from them cannot avoid a similar difficulty as the case of the fish recruited in the period i). At present we predict the size of $\underline{a}$-th year class, $\underline{P}_{\underline{a}}$, in the major exploitable phase from relative abundance of III-age fish, $\underline{S}'_{\underline{a}.3}$, on the basis of data of longline catch in March. The index, $\underline{S}'_{\underline{a}.3}$, is calculated through formula 3) which resembles formula 2).

$$\underline{S}'_{\underline{a}.3} = \sum_{\underline{i}} \underline{r}_{\underline{a}+3.3\underline{i}} \, \underline{X}_{\underline{a}+3.\underline{i}} \qquad \text{..............} (3)$$

Table XIII

Relative abundance and the number of catches of each year-class in the Northwest Pacific before main recruitment to this area begins at the end of III-age in March

(1)	1946	1947	1948	1949	1950	1951	1952	1953	1954	ρ_n	(7)
(2)	4.26	2.43	3.11	0.72	0.70	1.42	2.90	2.03	1.47	-----	
(3)	-	-	-	-	6.90	0	0	0	0	ρ_3	=-0.69
(4)		0.01	0.01	0.03	0.03	0.04	0.05	0.01	0.08	ρ_4	=-0.27
(5)	-	-	-	140.4	16.8	1.9	15.9	97.1	76.3	ρ_5	=-0.28
(6)	0.10	0.22	0.13	0.35	0.38	0.83	0.27	0.62	0.30	ρ_6	=-0.55

(1) Year-class

(2) Population size of year-class (Index-P)

(3) Number of fish of year-class caught as II-age by pole-and-line

(4) Hooking rate of year-class caught as II-age by longline

(5) Number of fish of year-class caught as III-age by pole-and-line

(6) Hooking rate of year-class caught as III-age by longline

(7) Coefficient of correlation with Index-P

Table XIV

Comparison between the Albacore landings in U. S. A. and the indices to relative abundances in the Northwest Pacific off Japan

	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	(a)	(b)
(1)	2.74	3.62	1.72	2.63	1.74	1.35	1.49	2.03	2.33	1.92	2.14		
$\overline{S}$	2.72	3.35	4.60	4.25	2.83	2.12	1.50	3.15	2.98	2.38	1.97	$\rho_{35}=+0.35$	$\rho_{37}=+0.58$
L				5.04	3.40	1.99	1.75	4.25	3.81	1.74	1.09	$\rho_{36}=+0.61$	$\rho_{38}=-0.05$

(1): The amount of landings in U. S. A.

$\overline{S}$: Index to relative abundance in longline season of the Northwest Pacific (See Table IX).

L: Index to relative abundance in pole-and-line season of the Northwest Pacific (See Table IX)

(a): Coefficient of correlation with the amount of landings in U. S. A. in the same year

(b): Coefficient of correlation with the amount of landings in U. S. A. in the preceding year

Note: ρ_{35} is calculated as +0.76 on the basis of data from 1952 to 1959

ρ_{36} is calculated as +0.11 on the basis of data from 1952 to 1959

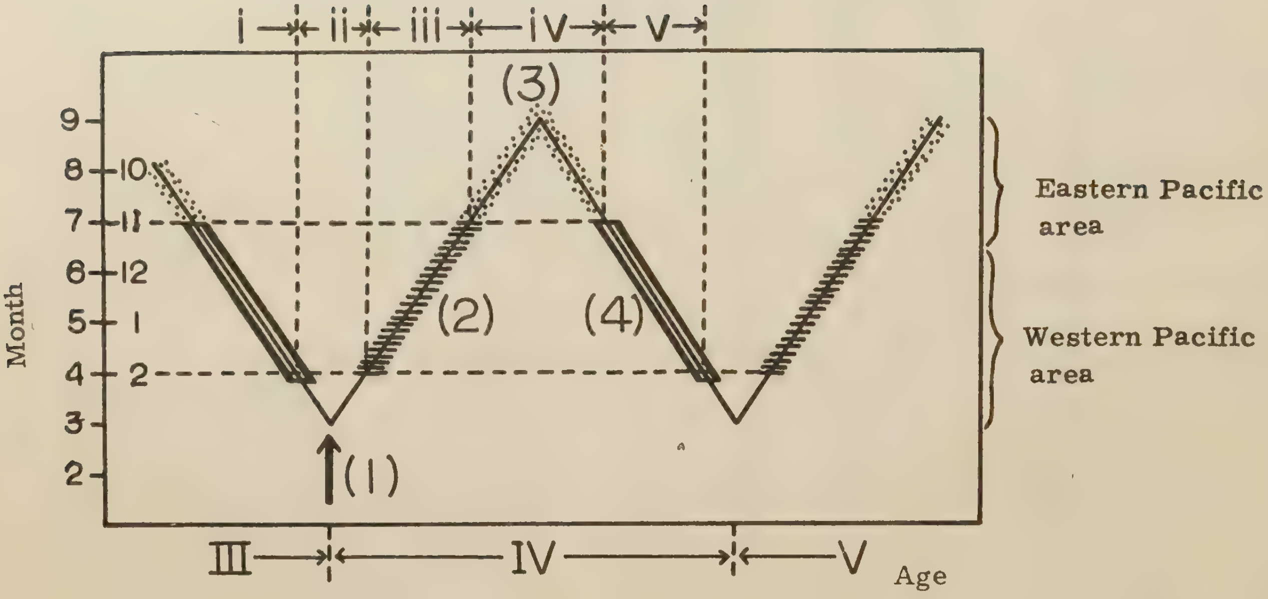
i
ii
iii
iv
v
(3)
(2)
(4)
(1)
Month
9
8
7
6
5
4
3
2
10
11
12
1
2
Eastern Pacific area
Western Pacific area
III
IV
V
Age

Fig. 20 Schematic presentation of exploitation process of a year-class in the Northern Pacific

(1) Recruitment
(2) Pole and line fishing season (Eastward migrating season)
(3) Trolling and pole-and-line fishing season
(4) Longline fishing season (Westward migrating season)

$r_{a+3.3i}$: ratio of III-age fish in i-th sub-area in March of a +3th year

$X_{a+3.i}$: hooking-rate of III-age fish in i-th sub-area in March of a+3th year.

The index $S'_{a.3}$, is not well correlated with the abundance of the year-class, P_a. The correlation coefficient between $S'_{a.3}$ and pole-and-line catch of the year-class in IV-age is about 0.60, indicating that the former is hardly suitable for predicting the latter (Table XVI). The following two points should be examined to test reliability of this method of prediction.

1) It is worth trying to use for the prediction data of catch in April instead of March, since year-to-year change of the recruitment season seems to make the prediction unreliable.

2) Year-to-year change of availability also makes the prediction unreliable. Among the seven year-classes under discussion, the 1952 class seems to have received a particularly strong environmental influence upon their migration into the fishing ground. But the discrepancy between the predicted and the actual catch is mainly attributed to the fact that the former is based on data of a minor portion of the stock. For this reason, we have to accumulate, as pointed out in 5.1.1, knowledge on the stock in the pre-exploited phase.

Let us consider predictability of the total stock sizes in a year, L and $\bar{S}$. In this case, the prediction is based on IV-age fish exploited in the preceding season as well as III-age fish being recruited. The abundance in March is correlated with L and $\bar{S}$ in the forthcoming year (as in Table XV) under the assumptions that, among portions of the age groups exploited in March, there will appear again in the fishing ground in the succeeding season one of these groupings:

1) all of them

2) only III- and IV-age fish

3) all of III-age and a half of IV-age fish, or

4) only III-age fish.

The index $\bar{S}$ is predicted under the assumption 2. As shown in Table VII-a, IV and V-age fish comprise about 70 percent of the longline catch and are almost equivalent with each other in the stock size. For this reason, abundances of III- and IV-age fish in a season are adopted for predicting the index $\bar{S}$ in the forthcoming season.

The index L is predicted under assumption 3. In Table VII-a, ratio between IV- and V-age fish caught by pole-and-line is about 2:1. For this reason, stock sizes of all III-age fish and a half of IV-age fish in a season are used for predicting the index, L, in the coming season.

In March, however, III-age fish are not completely recruited into the fishing ground, so that the recruited size of them may cause underestimation of the abundance of IV-age fish in the succeeding season. Therefore, the size of IV-age fish estimated in 2) and 3) is corrected by the assumptions 3 and 4, respectively.

In Table XV some of these methods are fairly reliable in predicting the stock, especially that between 140° and 160°E. For another area from 130°E to 150°E, the predicted and the actual stock sizes are not highly correlated with each other, probably because of influences of oceanographic conditions in an area between 130°E and 135°E or 140°E, especially the former. The prediction of the stock size is possibly affected also by the older fish which are staying there before they leave for the North Equatorial Current by the next season. As the data before 1954 are inconclusive, the correlation coefficient, ρ'_n, is calculated on the basis of data taken in 1954 and onward. Among these correlation coefficients, the value based on the assumption 3 is especially high. It is noted that the stock sizes of IV- and III-age fish play major roles in predicting $\bar{S}$ and L, respectively. There is no reason but sampling error to explain a phenomenon that ρ_{10} (Table XVI) is smaller than ρ'_{33}. The reliability of this prediction will be improved if we take into account such oceanographic conditions as pointed out by Uda (1940), Kawasaki (1957), and Inoue (1959, 1960).

5.1.3 Prediction of stock for longline from pole-and-line catch in the period iii)

The stock in period iii) seems to provide more reliable data for the prediction than in the periods i) and ii), because by this period the major portion of the stock has been recruited in the pole-and-line ground to be exploited on a

Table XV

Correlation between hooking-rate of albacore in March in n-th year calculated by several ways and the indices $-\overline{S}$ and -L to relative abundances in n+1-th year

		1952	1953	1954	1955	1956	1957	1958	1959	(a)	(b)	(c)	(d)
Index-L		5.04	3.40	1.99	1.75	4.25	3.81	1.74	1.09				
Index-$\overline{S}$		4.25	2.83	2.12	1.50	3.15	2.98	2.38	1.97				
	130° - 180°E	4.24	3.10	1.91	1.24	1.45	3.14	3.10	2.18	$\rho_{11}=+0.50$	$\rho_{12}=+0.72$		
(1)	130°-160°E	4.70	3.37	1.94	1.22	1.76	3.33	2.72	1.64	$\rho_{13}=+0.70$	$\rho_{14}=+0.84$	$\rho'_{15}=+0.41$	$\rho'_{16}=+0.61$
	140°-160°E	5.83	3.85	2.33	1.33	1.96	3.72	3.08	1.60	$\rho_{15}=+0.73$	$\rho_{16}=+0.85$		
	130°-150°E	4.40	2.80	2.18	1.44	1.69	2.84	2.46	1.61	$\rho_{17}=+0.69$	$\rho_{18}=+0.84$		
	130°-160°E	2.92		1.66	1.05	1.74	3.28	2.19	1.57	$\rho_{19}=+0.66$	$\rho_{20}=+0.75$		
(2)	140°-160°E	3.85		1.89	1.25	1.94	3.60	2.28	1.51	$\rho_{21}=+0.77$	$\rho_{22}=+0.85$	$\rho'_{21}=+0.59$	$\rho'_{22}=+0.70$
	130°-150°E	2.33	2.52	2.07	1.22	1.65	2.84	2.41	1.52	$\rho_{23}=+0.45$	$\rho_{24}=+0.54$		
	130°-160°E	1.99		1.52	0.94	1.53	2.52	1.71	0.92	$\rho_{25}=+0.68$	$\rho_{26}=+0.68$		
(3)	140°-160°E	2.15		1.74	1.20	1.78	2.63	1.80	1.05	$\rho_{27}=+0.72$	$\rho_{28}=+0.69$	$\rho'_{27}=+0.72$	$\rho'_{28}=+0.76$
	130°-150°E	1.47	2.18	1.93	1.07	1.54	2.47	2.03	1.38	$\rho_{29}=+0.20$	$\rho_{30}=+0.22$		
	130°-160°E	1.03		1.36	0.82	1.40	1.74	1.23	0.86	$\rho_{31}=+0.42$	$\rho_{32}=+0.32$		
(4)	140°-160°E	1.54		1.58	1.14	1.62	1.63	1.31	0.57	$\rho_{33}=+0.71$	$\rho_{34}=+0.56$	$\rho'_{33}=+0.76$	$\rho'_{34}=+0.63$
	130°-150°E	0.56	1.74	1.78	0.93	1.41	2.08	1.62	1.24	$\rho_{35}=-0.13$	$\rho_{36}=-0.22$		

(1) Hooking-rate for the sum of all age groups in March of n-th year
(2) Hooking-rate for the sum of III-age group and IV-age group in March of n-th year
(3) Hooking-rate for the sum of III-age group and half of IV-age group in March of n-th year
(4) Hooking-rate for III-age group in March of n-th year

(a) Coefficients of correlation between hooking rates and index-L from 1952 to 1959
(b) Coefficients of correlation between hooking rates and index-$\overline{S}$ from 1952 to 1959
(c) Coefficients of correlation between hooking rates and index-L from 1954 to 1959
(d) Coefficients of correlation between hooking rates and index-S from 1954 to 1959

Table XVI

Comparison between relative abundance and number of catches of a given year-class at several different points of the life history

	Area	1948	1949	1950	1951	1952	1953	1954	1955	(a)	(a)	(b)
S_{a3}	130-160°E	1.03		1.31	0.82	1.40	1.74	1.23	0.86	$\rho_7=+0.06$	$\rho'_7=+0.37$	$\rho_9=+0.54$
	140-160°E	1.54		1.58	1.14	1.62	1.63	1.31	0.57	$\rho_8{}^*=+0.38$	$\rho'_8{}^{**}=+0.35$	$\rho_{10}=+0.67$
P		3.11	0.72	0.70	1.42	2.90	2.03	1.47				
L_{a4}		195	146	122	174	326	234	143	79			

S_{a3}: relative abundance recruited in the Northwest Pacific at the end of III-age in March

L_{a4}: number of III-age fish caught during the pole-and-line season in the Northwest Pacific (See Table I)

P: relative abundance calculated by equation (2) on the basis of longline season data (See Table I) in IV- and V-age

*: 1948-1955 year-class

**: 1950-1955 year-class

(a): coefficient of correlation with Index-P

(b): coefficient of correlation with Index-L_{a4}

large scale. As mentioned in section 2.4, the stock size exploited by pole-and-line, $\underline{L}$, is correlated with mean hooking-rate by longline $\overline{S}$, a half-year later at a coefficient of 0.92. Therefore, use of this correlation enables us to predict the index, $\overline{S}$, at a high accuracy; a variation coefficient of the predicted stock may be about 40 percent of that of $\overline{S}$, 30 percent. Therefore, the index, $\underline{L}$, may suffice to predict the value of $\overline{S}$ with a confidence interval of 25 percent at a significance level of 10 percent. If data on availability are obtained, we may be able to predict the index, $\overline{S}$, at an accuracy high enough for the commercial purpose.

5.1.4 Prediction based on the northeastern Pacific catch in period iv)

Since the data from which catch per unit effort was computed for the stock in the northeastern Pacific off North America (Partlo 1955a; Schaefer 1955; Griffiths 1960) are not available now in Japan, we refer to total albacore landings in the United States (Anderson *et al* 1953; Partlo 1955b; Van Campen 1960) as an index of the stock size in the northeastern Pacific. Absence of pole-and-liners from the northwestern area in period iv) permits the index $\overline{S}$ to represent the stock size therein. In Table XIV the correlation is unexpectedly low between these two measures of the stocks on both sides of the North Pacific. The ecological relation between them proved in tagging experiments, however, retains possibility to advance this method of prediction when sufficient data on the stock size are made available from the northeastern area.

Some points needing investigation to improve the prediction method are:

1) Low reliability of catches landed on the U.S. west coast mainly by small trollers, the amount of whose effort would remarkably vary depending on oceanographic conditions (Anderson *et al* 1953).

2) Local differences of age composition of catch that seemingly exist between both sides of the North Pacific (Table I).

3) Doubtfulness whether the commercial catch really represents the stock most probably scattered over a wide longitudinal range from 25°N to 60°N along the west coast of North America, even if the amount of effort were constant.

5.1.5. Prediction from longline catch in period v)

Around the end of the longline season, III-age fish are recruited to the major exploitable phase and V-age fish, having stayed in the fishing area for a year, leave for the spawning area (see section 2.4) while IV-age fish remain in the fishing area and become V-age after the end of period v). Since V-age fish constitute only 30 percent of the longline catch and still less of pole-and-line catch, however, it may be concluded that IV-age fish exploited by longline in period v) provide too little information to predict from it the stock size available for the subsequent pole-and-line and longline seasons. In fact this conclusion seems to be supported by the correlation coefficient that was calculated at only 0.4 between mean hooking-rate of longline and pole-and-line catch a half-year later (see section 2.4 and Fig. 11-b).

5.2 Indirect prediction from evidence other than stock size

The size of major exploitable stock is predictable to some extent from a portion of the stock available as early as period i) by the use of evidence other than stock size. Take, for instance, the correlation between mean body length of II-age fish and the year-class strength (see section 4.2). The correlation, with the coefficient reaching to -0.69, calls attention in regard to the prediction. But the author does not recommend using a correlation of this kind for prediction, even if it is high enough, as more than an incidental bit of information, unless a biological implication of the correlation is explicit, or two or more sets of such information become available simultaneously.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Relevant to the present studies it may be concluded that:

1) Albacore in the North Pacific areas belong to a single stock.

2) As the commercial fisheries exploit the immature members of the stock most, the annual harvest including, at least pole-and line catch and longline catch in the northwestern Pacific, depends upon the size of the exploitable stock.

3) No substantial information has been clarified on mechanisms underlying fluctuation in the size of the exploitable stock.

4) It is possible to predict the fishing conditions to some extent, particularily the stock size available for longlining, on the basis of the pole-and-line catch made a half-year before, in period iii), but to advance the prediction, information should be secured for fish in the pre-exploitable phase.

6.2 Recommendation

Future research should stress the following:

1) We have to know the size of recruitment as early as possible before the exploitable phase. At this stage it is not always necessary to clarify mechanisms of fluctuation in the recruitment. Instead, it will suffice to determine the size of the stock that is being recruited to the fishing area. The first step to take for the study is perhaps to secure ecological information of the young albacore in the pre-exploitable phase.

2) Next we have to examine fluctuation in the recruitment of the albacore in association with the related species. For there are indications that the stock size of bigeye tuna fluctuates in a similar trend with the albacore (see section 4.2); the stock size of the bluefin tuna, Thunnus orientalis, seems to be in negative correlation with the albacore (Suda, Tatsuki and Uto 1959); the striped marlin stock has increased every two years (Ueyanagi 1954). These facts suggest that the albacore stock in its fluctuation receives strong influences from factors also governing stock sizes of the related species as well as from factors particular to this species. It may be effective for developing the research to study the fluctuations in the related species inhabiting the North Pacific as a whole, including the albacore, bigeye tuna, swordfish, and bluefin tuna. If necessary, the study should be expanded to include the yellowfin tuna which has a habitat apart from the albacore.

Experience Paper No. 16

SEASONAL AND ANNUAL VARIATION OF THE HOOKING-RATE AND ANNUAL VARIATION OF THE CATCH-QUANTITY OF TUNA AND MARLIN IN THE TROPICAL ATLANTIC OCEAN

By

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Abstract

The longline tuna fishing grounds of the Atlantic Ocean were fished for the first time by a Japanese vessel in 1955. Since then, these grounds have become an important source of tuna for export. In 1960 the longline catch from this area of the Atlantic amounted to 72, 946 metric tons.

The catch data for 1957 to 1961 are summarized by species, by season, and by year for sub-area of the fishing grounds. Good and poor seasons are defined by sub-area for yellowfin, bigeye, albacore and blue marlin.

The hooking-rate for yellowfin has been declining since 1958. For bigeye in one sub-area the hooking-rate has been high in odd years and low in even years, but in other sub-areas the catch has varied irregularly. The rate for albacore has been declining since 1959. The mode of the length and the mean fork length of both yellowfin and albacore in the catch were less in 1960 than in 1957.

VARIATIONS SAISONNIERES ET ANNUELLES DU TAUX DE CAPTURE ET VARIATION ANNUELLE DES PRISES DE THONS ET DE MARLINS DANS L'ATLANTIQUE TROPICAL

Résumé

C'est en 1955 qu'un bâtiment japonais a opéré pour la première fois sur les lieux de pêche aux palangres du thon dans l'Atlantique, devenus depuis lors une importante source de thon destiné à l'exportation. En 1960, les captures de thon faites aux palangres dans cette zone de l'Atlantique se montaient à 72 946 tonnes.

Le document fournit pour 1957-1961 des données sur les prises groupées par espèces, par campagne et par année par sous-zones des lieux de pêche, en indiquant pour chacune les bonnes et les mauvaises campagnes pour le thon à nageoires jaunes, le thon obèse, l'albacore et le marlin bleu.

Le taux de capture du thon à nageoires jaunes est en régression depuis 1958. Pour le thon obèse, dans une des sous-zones, il est élevé les années impaires et bas les années paires, tandis qu'il varie irrégulièrement dans les autres sous-zones. Le taux de capture de l'albacore est en baisse depuis 1959. On a constaté, tant pour le thon à nageoires jaunes que pour l'albacore, que le mode ainsi que la moyenne de la longueur à la fourche avaient en 1960 une valeur moins élevée qu'en 1957.

VARIACION ANUAL Y ESTACIONAL DEL PROMEDIO DE CAPTURAS POR ANZUELO, Y VARIACION ANUAL DE LAS CANTIDADES DE CAPTURA DE ATUN Y PEZ AGUJA EN EL ATLANTICO TROPICAL

Extracto

La pesca del atún con palangre en el Atlántico fue practicada por primera vez, por un barco japonés, en 1955. Desde entonces, aquellas pesqueras han constituido una importante fuente de atunes para la exportación. En 1960, la pesca con palangre en esta zona atlántica ascendió a 72.946 toneladas métricas.

Se resumen aquí los datos de captura de 1957-1961 por especies, campañas y años para las subzonas de pesca. Se definen, por subzonas, las campañas buenas y malas para el atún de aleta amarilla, el patudo u obeso, la albacora y el pez aguja de casta.

El promedio de capturas de atún de aleta amarilla por anzuelo ha venido disminuyendo desde 1958; para el patudo, en una subzona, dicho promedio ha sido alto en los años impares y bajo en los pares, pero las capturas de las demás subzonas han tenido variaciones irregulares. El promedio correspondiente a la albacora disminuye desde 1959 en adelante. El modo de longitud y la longitud media a la horquilla fueron en 1960 inferiores a los de 1957, tanto para las capturas de atún de aleta amarilla como para las de albacora.

1 INTRODUCTION

The tuna longline fishing grounds in the Atlantic Ocean were fished by No. 13 Kaiko-Maru in 1955 as the first test of these grounds by a Japanese commercial fishing vessel. Since then the fishing ground has been developed so widely that now it is highly regarded as an important source of supply of frozen tuna for export. In 1960 a catch of 72,946 metric tons was made in the Atlantic by Japanese fishing vessels alone. It is thought that in the future an increasing importance will be attached to investigations and researches into the resources of this Ocean.

Fig. 1 shows the number of voyages of Japanese fishing vessels to the equatorial waters of the Atlantic and, in Table I, the number of entries at foreign ports by these fishing vessels. In respect to reports on investigations of the fishing grounds of these waters, there are manuscripts in preparation on cruises of the Sagami Maru, Shoyo Maru and Boso Maru. Regarding the distribution of the fish species, there are publications by Nagai and Nakagome (1958), Nakamura and Kamimura (1958), Nagai et al. (1959) and Rosa and Laevastu (1961). Concerning the annual variation of hooking-rate of yellowfin tuna by sub-area, there is a recent paper by Nagai, Kawaguchi and Nakagome (1961).

As regards the seasonal and annual variation of the hooking-rate of the fish of the Atlantic, there is as yet no publication on tuna species other than yellowfin, and on this species only fragmental reports exist. Further, as the only existing reports on the seasonal variations of the hooking-rate of yellowfin tuna had been done by large area, it could not be analyzed and rearranged into smaller sub-areas. Moreover, there has sometimes been doubt as to the number of hooks used. Therefore, as a matter of necessity, we have had to re-examine the previously reported annual variation in the hooking-rate of yellowfin tuna in the Atlantic.

In view of the above-mentioned problems, we tried to collect as much data and information as possible in preparation for compiling the present report, requesting cooperation of companies and private owners of fishing vessels and their captains. For the sake of ensuring accuracy we even obtained direct wireless communications from the Atlantic operating vessels whenever doubtful or unknown points were met. We have analyzed these data and have examined seasonal and annual variation of the hooking-rate for each species in the catches and particularly the yearly variation of the catch-quantity of yellowfin tuna.

The authors hereby express their whole-hearted thanks to all the fishing companies, private owners and captains of the fishing vessels who have cooperated with them in the collection of these data. If this report should be of any use to those directly engaged in the fishery and to any researchers interested in the subject, the honor and pleasure are those of the authors.

2 MATERIAL AND METHOD

The data have been collected mainly from log books of vessels, which had been kept by the fishing companies, but some data have been obtained directly from fishing vessels.

The data for 1957 and 1958 were used in the report by Nagai and others (1959). The data for 1959 were employed in the report by Nagai, Nakagome and Fukuoka (1960). [As for 1960, new collections were added to the data which had been used in the report by Nagai, Kawaguchi and Nakagome (1961).] In respect to the data for 1959, 1960 and 1961, in which the number of hooks used had been uncertain, accurate values were obtained via wireless directly from the fishing vessels.

The hooking-rate is expressed as the number of fish caught per 100 hooks. In this report the authors have used the hooking-rate calculated by month and by small sub-area consisting of each 5 degrees of latitude and longitude (Fig. 2).

The seasonal and annual variation in hooking-rate has been expressed by large sub-area (Fig. 2) and by year by summarizing the hooking-rate for small sub-areas by month as aforementioned. The annual variation of hooking-rate has been shown by large sub-areas (hereinafter called just "sub-area") by summing values of the monthly hooking-rate by small sub-area aforementioned, and arranging by seasons as shown in Table II, according to the seasonal variation of the hooking-rate and pursuant to Nakamura's March and September Movement Theory. In regard to the annual variation in catch-quantity, comparison has been made between October-November, 1957 and October-

Table I

Number of entries at foreign ports[1] by Japanese tuna fishing vessels fishing in the Atlantic Ocean 1957 to 1961

Name of port	Country	Landed					Utilized as stocking, etc.				
		57	58	59	60	61	57	58	59	60	61
Freetown	Sierra Leone				19	44				18	41
Dakar	Senegal			11[2]	9	27			17[2]	13	44
Las Palmas	Canary Islands				7	11				6	12
Copar	Yugoslavia			4	15	6			1	6	3
Trieste	Italy				1	1	2	2	1	7	3
Venice	"	15	21	12	22	9	16	16	20	23	10
Bari	"	1	3	3	2	1	1			12	
Trapani	"	2	8	7	10	9	1	4	6	8	5
Palermo	"	3	5	5	10	3		3	2	5	5
Toulon	France			3	9				1	9	
Mar del Plata	Argentina			6	10	1			7	6	
Montevideo	Uruguay									6	1
Santos	Brazil		5	6		3		5	6		3
Rio de Janeiro	"	2	6			1		8	2		
Sao Salvador	"	5	6		2		3	2	2		1
Recife	"	18	26	26	6	12	25	33	27	14	14
Port-of-Spain	Trinidad		7	13	29	16		7	14	33	22
Barranqilla	Colombia			2	5	1			2	3	
Cristobal	Panama	2	12	22	24	18	2	15	29	25	20
Havana	Cuba	2	6	1	2	2	2	6	1	2	2
Port-au-Prince	Haiti		10	1				8	3		

[1] Less than five visits in a year: Casablanca, Bardia, Zuala, Tripoli, Haifa, Thessaloniki Belarca, Fiume, Ancona, Fabignana, Messina, Naples, Livorno, **Genoa, Marseilles,** Maceio, Natal, Fortaleza, Belem, Curaçao, Balboa, San Juan, Monrovia, Lagos, Hamburg, Abidjan

[2] Included calling at port

Table II

Periods of each year summarized in Figs. 7 - 9

Species	Sub-area	Period in r year
Yellowfin tuna	A, B, C, E.	From March in r year to February in (r+1) year
	D, F, G, H, I	From September in (r-1) year to August in r year
Bigeye tuna	B, E	From March in r year to February in (r+1) year
Albacore	E, G, I	From September in (r-1) year to August in r year

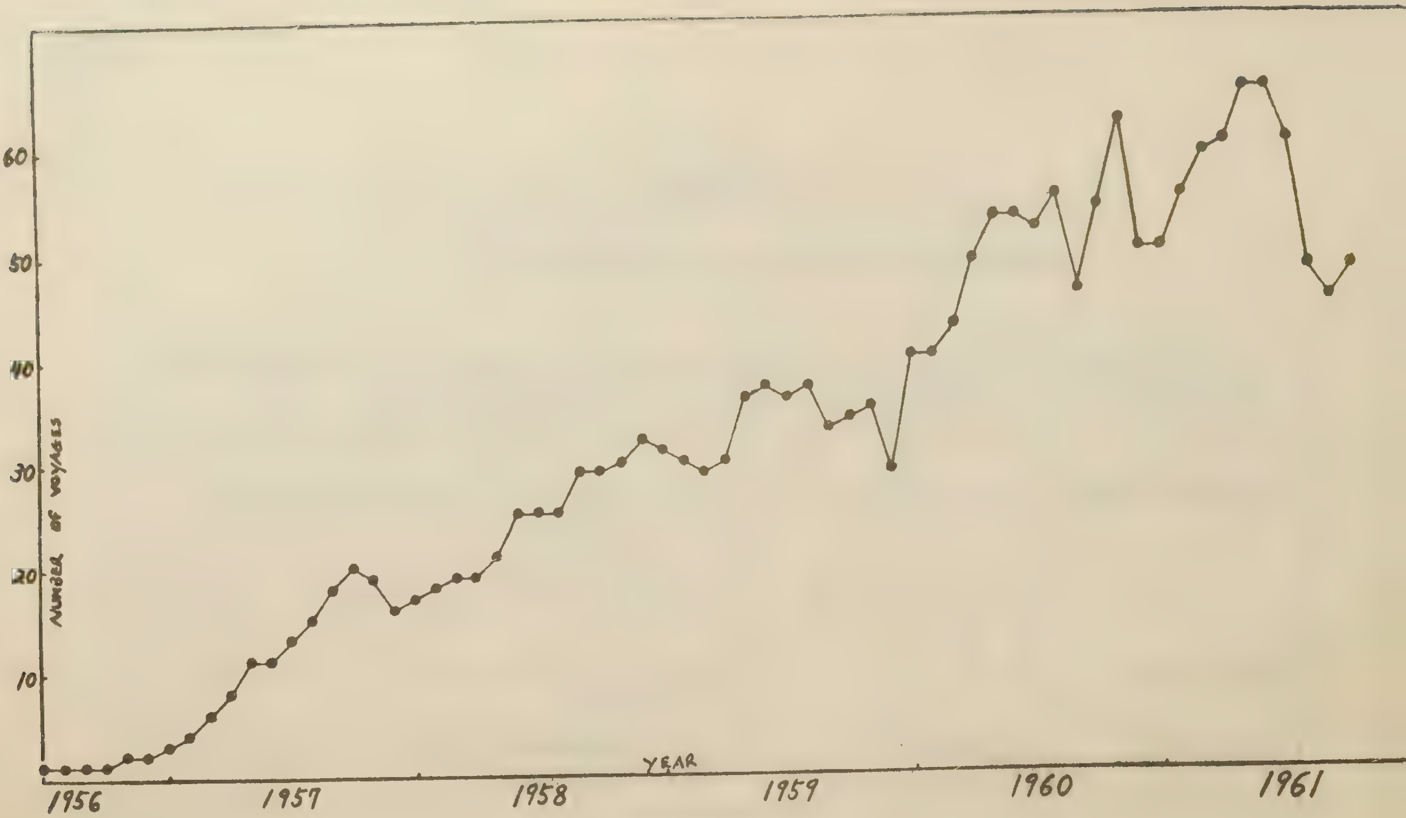

Fig. 1 Number of voyages, by month, of Japanese tuna fishing vessels in the Atlantic Ocean, 1956-61

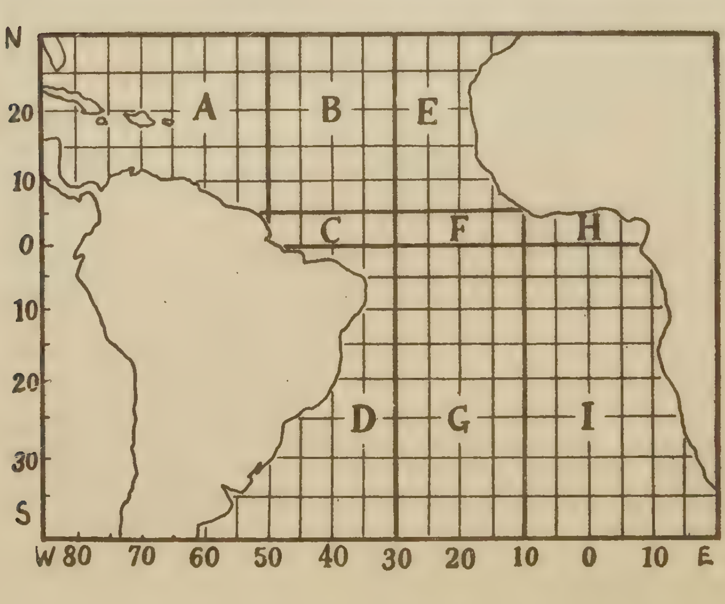
N
20
10
0
10
20
30
S
W 80
70
60
50
40
30
20
10
0
10
E
A
B
E
C
F
H
D
G
I

Fig. 2 Sub-areas of the Atlantic longline fishing grounds

November 1960 for sub-areas F and H by multiplying the mean body weight of fish, which was obtained from reports by Sagami Maru and Shoyo Maru, by the hooking-rates which had been calculated afresh after the number of hooks and the number of fish were re-arranged into large sub-areas.

3 SEASONAL VARIATION IN HOOKING-RATE

3.1 Yellowfin tuna

The seasonal variation in hooking-rate is shown in Fig. 3. In the case of yellowfin tuna, Neothunnus albacora (Lowe), May to September was a good fishing season and November to March was a poor fishing season for sub-areas A, B, C and E, while December to April was a good fishing season and June to October a poor fishing season for sub-areas F, G, H and I. These changes by season are in accord with the report by Nagai and others (1959) and that of Nagai, Nakagome and Fukuoka (1960). The results infer the possibility of a south-north seasonal migration quite similar to the migration in the Pacific Ocean as reported by Kamimura and Honma (1959).

Further, according to the report by Nagai and others (1959), a stock of fish remains in the region of latitude 2-5°N during November to February. The fact that the hooking-rate remains low in November to March in sub-areas A, B and C in spite of the above-mentioned situation (Fig. 3) seems to indicate that the main stocks of sub-areas A, B and C move toward sub-areas F, G, H and I in approximately the same period.

3.2 Bigeye tuna

Bigeye tuna, Parathunnus obesus (Lowe), shows a very similar seasonal variation throughout the sub-areas. May to October was a good fishing season but the hooking-rate declined somewhat in the month of July. December to March was a poor fishing season. This variation in the Atlantic resembles the fluctuation of the hooking-rate observed in the southwestern sea area of Java Island of the Indian Ocean as reported by Mimura and Nakamura (1959), but in the Atlantic the good fishing season started in the month of May, which was somewhat earlier than in the Indian Ocean. (Fig. 4).

3.3 Albacore

The fishing season for albacore, Thunnus alalunga (Bonnaterre), was good in October to November, again good in March to May, and poor in June to September, but fishing conditions in December to February are not known in sub-areas, A, B and E. In sub-areas D, G and I, November to March constituted a good fishing period and May to September provided a poor fishing period. The high hooking-rate obtained in sub-areas around the Equator in May to September appears analogous to conditions in the Pacific Ocean as reported by Nakagome (1959 a + b) and to the situation in the Indian Ocean as reported by Mimura (1957). Also the high hooking-rate found in sub-areas A, B and E in October to November and again March to May resembles the inshore waters of Japan. However, the low hooking-rate for May to September and the high value for November to March in waters of latitude 5-15°S differs from the variation in the Pacific Ocean as reported by Nakagome (1959 a + b) reported a high hooking-rate in April to May and in August to September (or November to December) but a low rate in the other months. These conditions differ also from the variation in the Indian Ocean, as reported by Mimura (1957), who found a high hooking-rate in May to September and a low one in November to March. (Figs. 5a, b, c).

3.4 Blue marlin

In sub-areas A, B, C, E, F and H, there was a good fishing season for blue marlin, Makaira ampla (Poey) in March to June and in September to November, but a poor fishing season in July to August and in December to February. This is very similar to the seasonal variation in hooking-rate of black marlin, Makaira mazara (Jordan and Snyder), of the Pacific Ocean as reported by Nakagome (1958), and we may infer the possibility of a south-north seasonal migration similar to the migration of black marlin in the Pacific Ocean as reported by Nomura (1955), Nakagome (1958), Anraku and Yabuta (1959) and Ueyanagi (1960). (Figs. 6a and b).

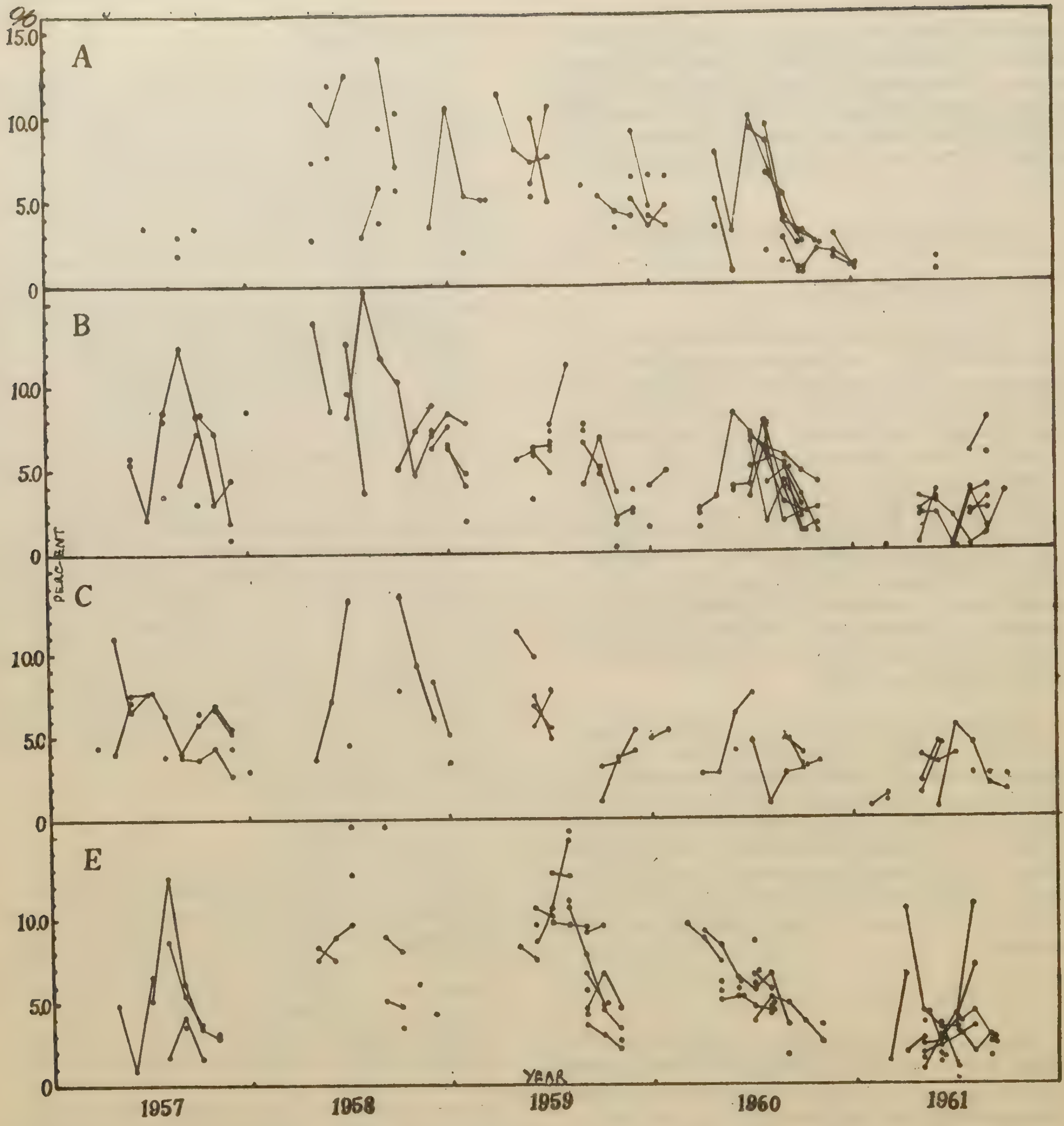

Fig. 3(a) Seasonal variation in hooking-rate of yellowfin tuna by sub-area.
Position of sub-areas shown in Fig. 2.

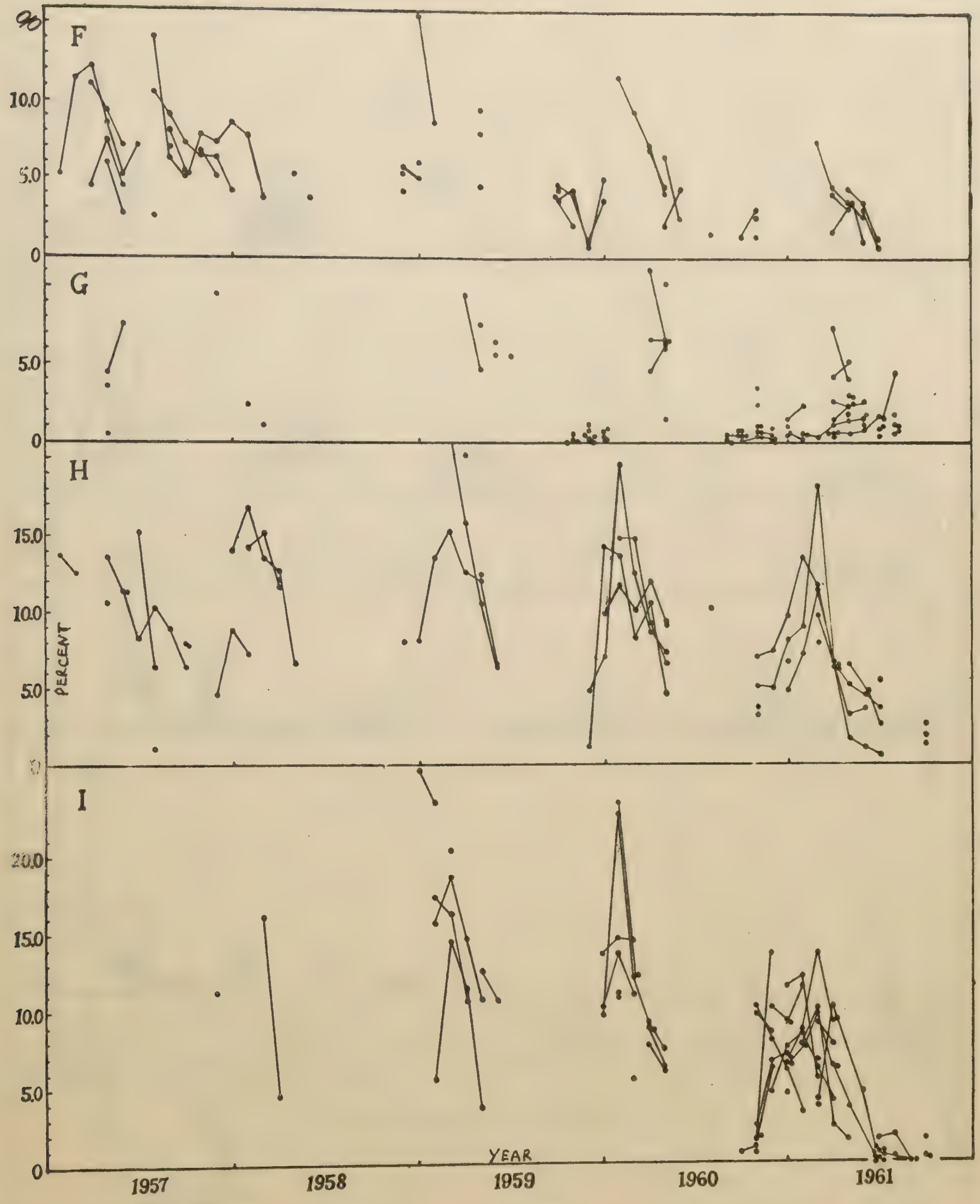

Fig. 3(b) Seasonal variation in hooking-rate of yellowfin tuna by sub-area. Position of sub-areas shown in Fig. 2.

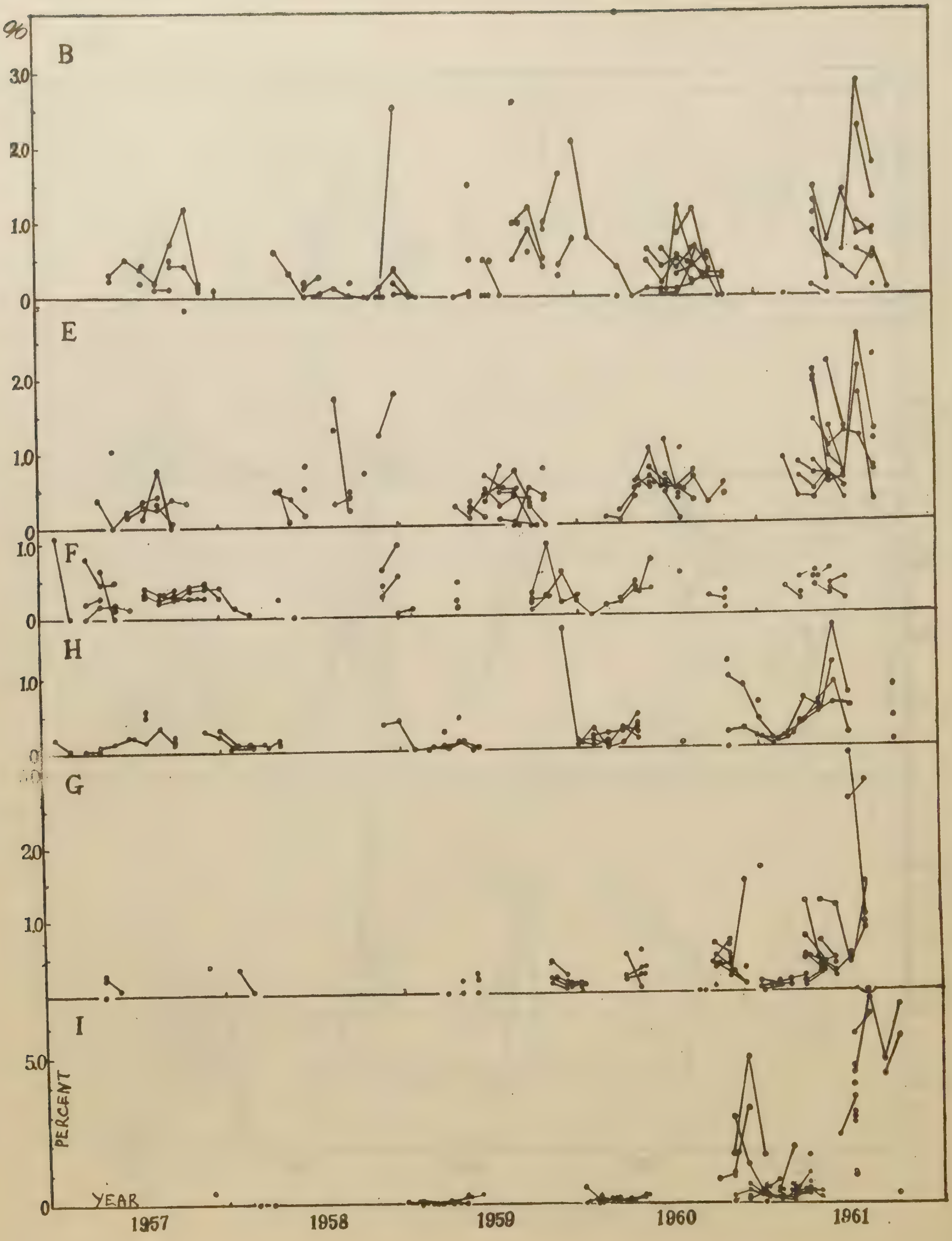

Fig. 4 Seasonal variation in hooking-rate of bigeye tuna by sub-area. Position of sub-areas shown in Fig. 2.

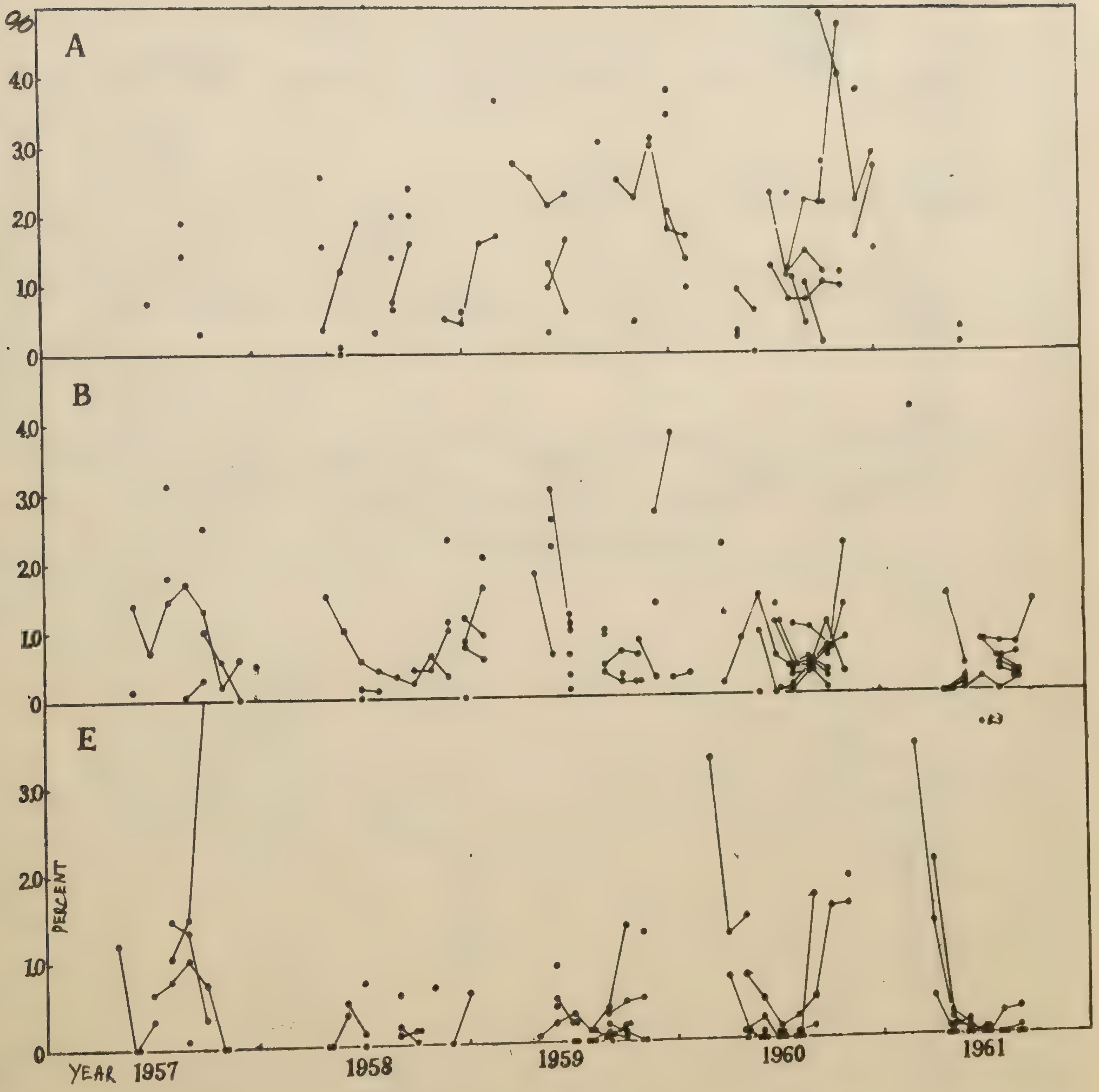

Fig. 5(a) Seasonal variation in hooking-rate of albacore by sub-area.
Position of sub-areas shown in Fig. 2.

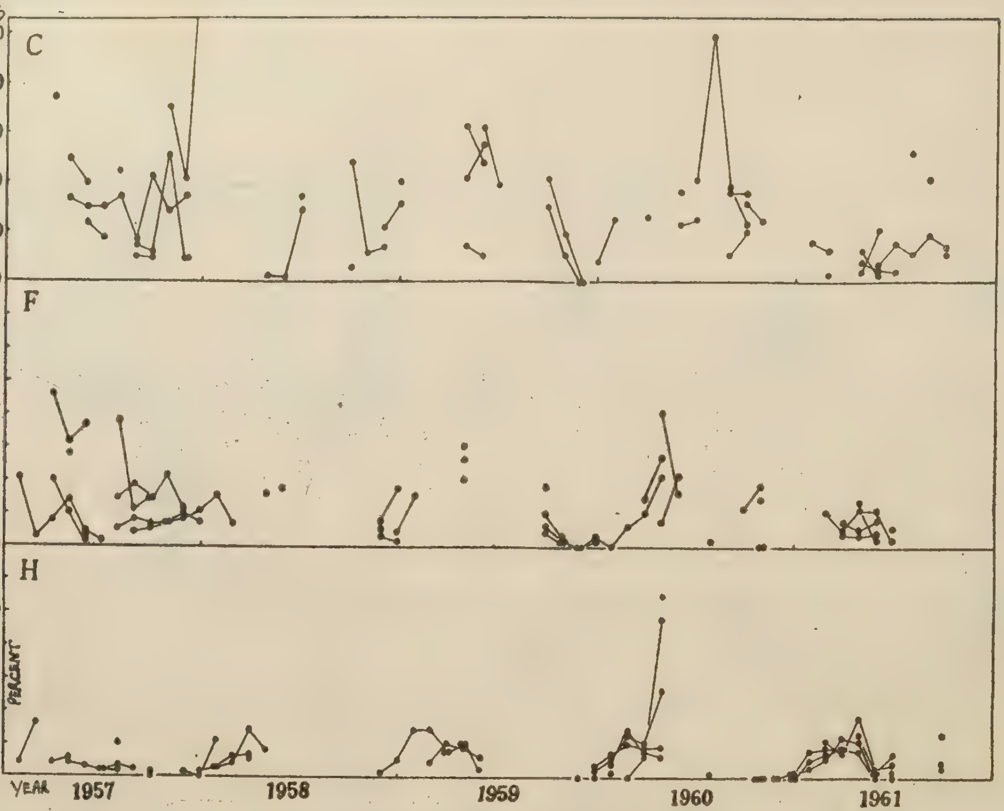

Fig. 5(b) Seasonal variation in hooking-rate of albacore by sub-area.
Position of sub-areas shown in Fig. 2.

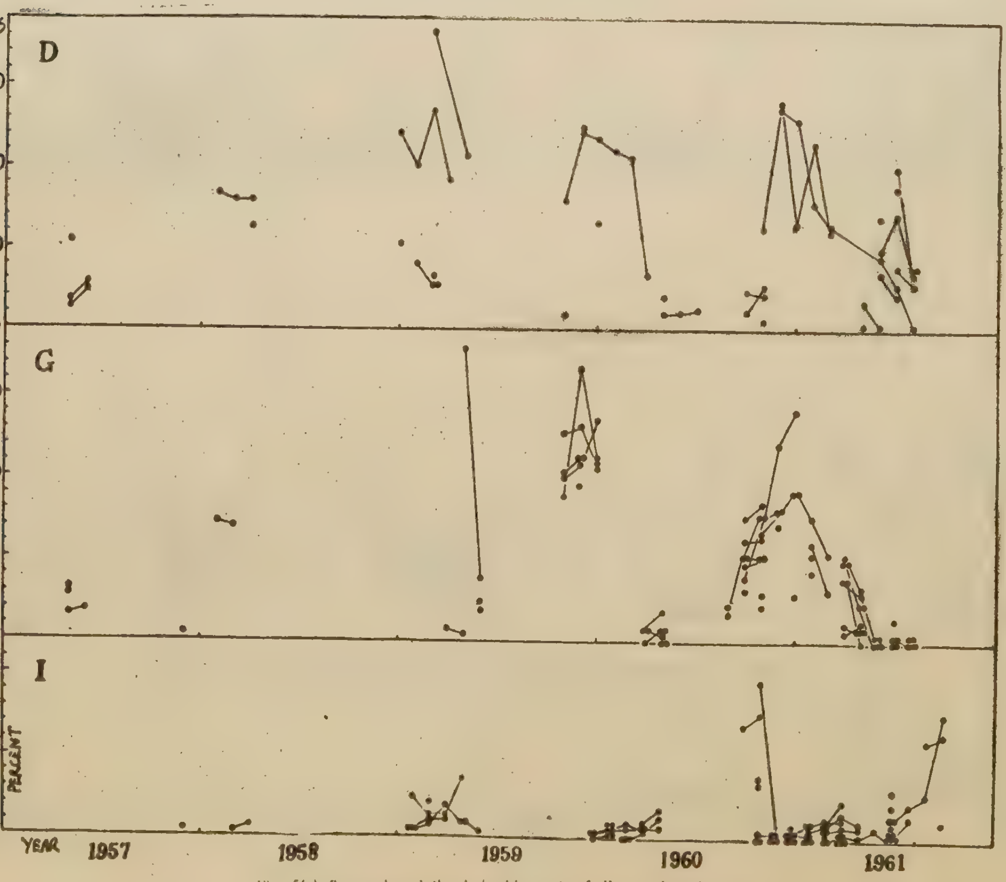

Fig. 5(c) Seasonal variation in hooking-rate of albacore by sub-area.
Position of sub-areas shown in Fig. 2.

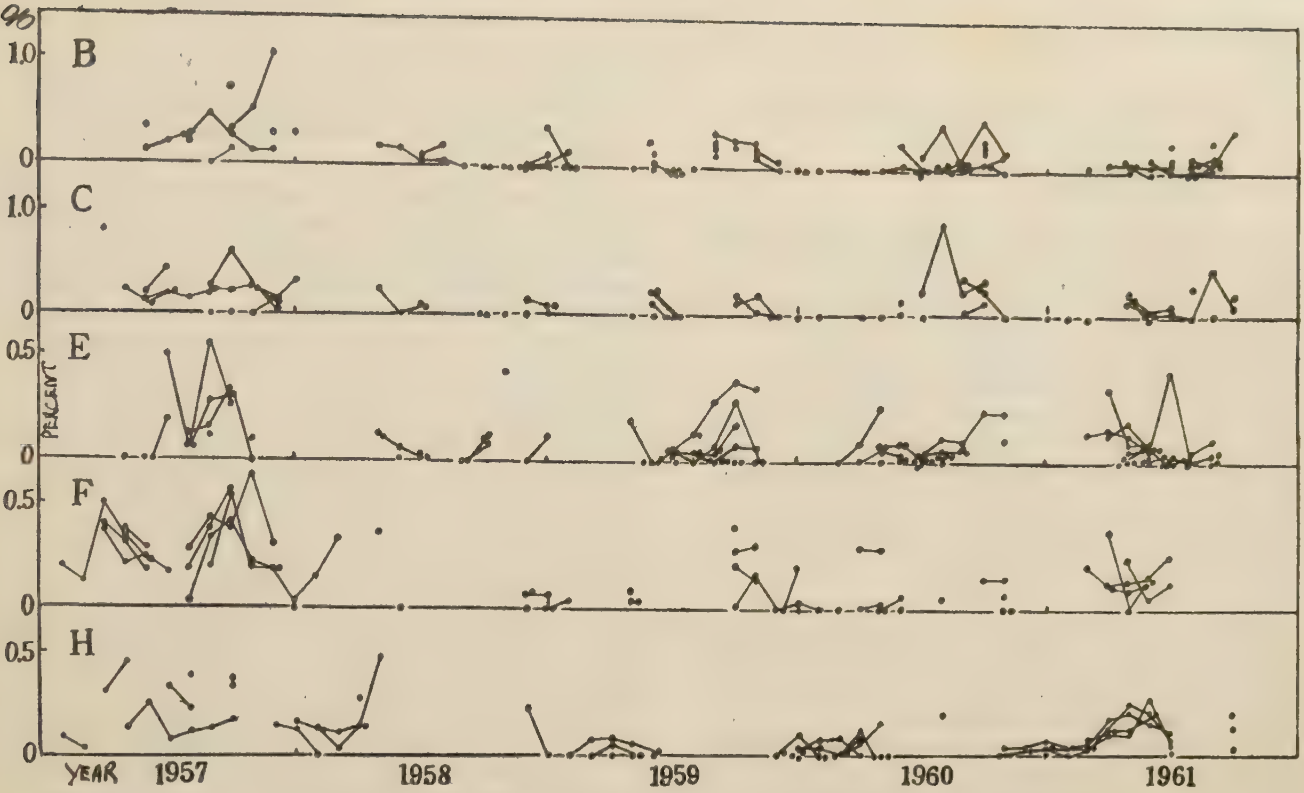

Fig. 6(a) Seasonal variation in hooking-rate of blue marlin by sub-area. Position of sub-areas shown in Fig. 2.

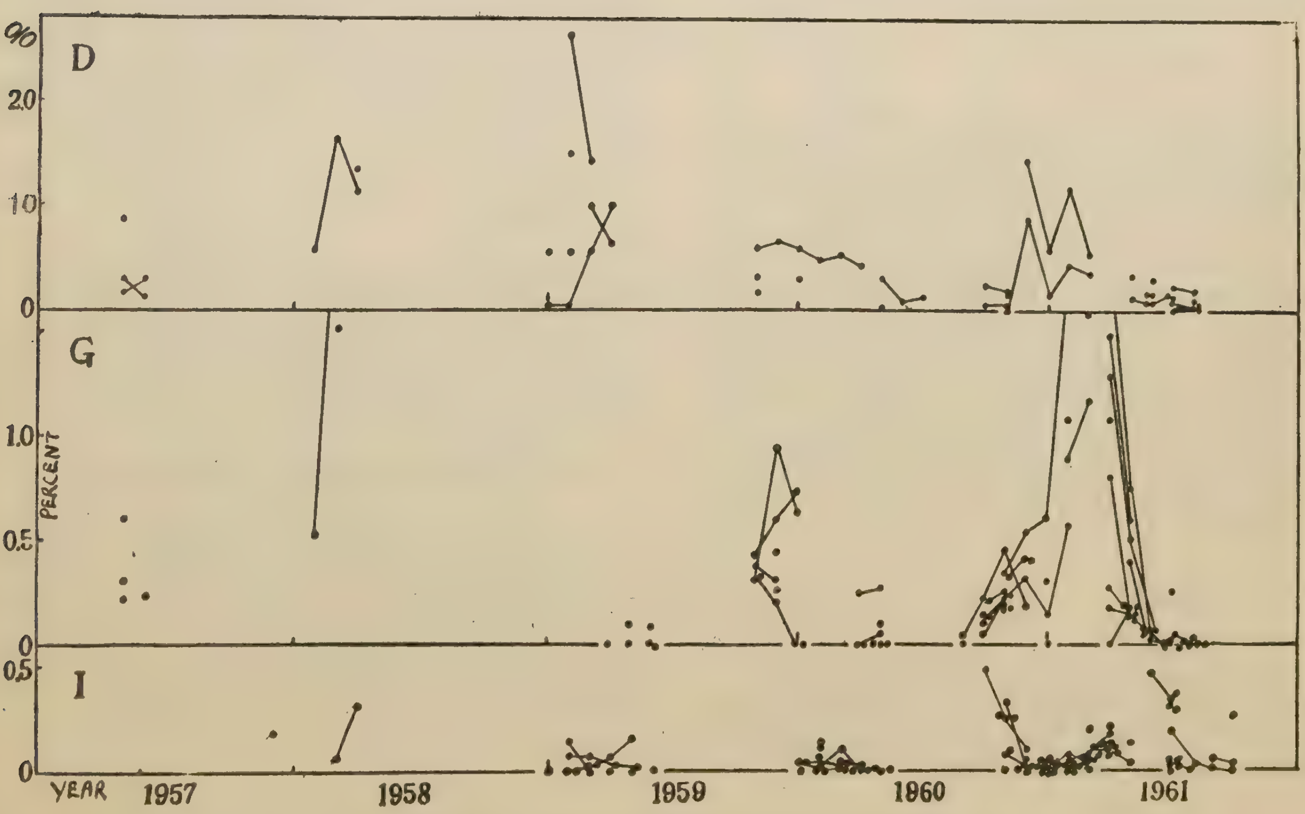

Fig. 6(b) Seasonal variation in hooking-rate of blue marlin by sub-area. Position of sub-areas shown in Fig. 2.

4 ANNUAL VARIATION OF HOOKING RATE

4.1 Yellowfin tuna

The yellowfin hooking-rate has shown a continual decline since 1958 in sub-areas A, B, C and E (Fig. 2). In sub-areas D, G, H and I there has also been a gradual decline since 1959. The marked decline of the hooking-rate in 1958 started with May to September season in sub-areas A, B, C and E, while the same trend began to happen conspicuously in December 1958 to April 1959 in sub-areas D, F, G, H and I. The good fishing season for the yellowfin is May to September for sub-areas A, B, C and E and December to April for sub-areas D, F, G, H and I.

This interesting phenomenon may be related to the observations of Kikawa (1959) who reported that spawning of yellowfin tuna in the Pacific Ocean occurs in April to November in the northern hemisphere and in November to March in the southern hemisphere. These periods coincide generally with the seasons when the catch showed its first marked decline in the northern and southern hemispheres.

4.2 Bigeye tuna

The hooking-rate for bigeye tuna for sub-areas G and I was extremely high. The bigeye fishing grounds of these sub-areas were first developed in 1961; therefore, the annual variation is still unknown. Some evidence of annual variation is shown by sub-areas B and E which are adjoining each other. In sub-area B the hooking-rate has been high in odd years and low in even years. The same two-year cycle has been found on the fishing grounds around the Midway Islands in the Pacific (Nakagome, 1958). On the other hand, in sub-area E, the hooking-rate was high in 1958 and 1961 and low in 1957, 1959 and 1960, so perhaps it is too early to draw definite conclusions. (Fig. 8).

4.3 Albacore

The hooking-rate for albacore, for which sub-areas D, G and I are the main fishing grounds, began to decline in 1959 in each of the sub-areas. The annual variation has been similar to that of yellowfin in the same sub-areas. (Fig. 9).

5 ANNUAL VARIATION IN CATCH-QUANTITY PER UNIT OF OPERATION (100 HOOKS)

The length frequency and the mean fork length of these tuna species captured at latitude 3-5° N, longitude 10-13° W in September to October 1957, and similar data for latitude 2° N - 10° S, longitude 1° E - 12° W for October to November 1960 are shown in Fig. 10. In respect to yellowfin tuna and albacore, both the mode and the mean fork length were less in 1960 than in 1957. In the case of bigeye tuna, there was a single mode at 140-160 cm in 1959 and two modes, one at 110-120 and the other at 150-170 cm in 1960. Therefore, in the annual variation of catch-quantity of yellowfin tuna per unit of operation between these years the decline in total catch in 1960 was accompanied by a decline in hooking-rate (Fig. 7) and a decrease in body length of the fish (Fig. 10) Table III provides a comparison, for yellowfin, of the annual difference in mean body weight which was calculated for the mean fork length by Nakagome's (1959b) conversion formula, and the catch-quantity per 100 hooks which was obtained by multiplying the mean body weight by the value of the hooking-rate. The annual variation of catch-quantity of bigeye tuna and albacore per unit of operation could not be examined from the present data since the hooking-rate of these species in the sub-area F and H has been extremely low.

6 SUMMARY

We have studied the seasonal variation and annual variation of longline catch-quantity and hooking-rate of yellowfin tuna and of some associated fish of the Atlantic Ocean in the region of the Equator, dividing the area into rectangles of 5 degrees each of latitude and longitude.

6.1 Seasonal variation of hooking-rate

In large sub-areas A, B, C and E, the good fishing season for yellowfin tuna opens in May and ends in September; the poor fishing season lasts from November to March. In sub-areas F, G, H and I, the good fishing season starts in December and ends in April, and the poor fishing season lasts from June to October.

Table III

Differences (and decreasing rates) in mean hooking-rate, mean body weight and catch-quantity per 100 hooks of yellowfin tuna captured in October to November in 1957 and October to November in 1960

Sub-area	Months compared		Year	1957	1960	Difference	Decreas-ing %
	1957	1960					
F, H	Sept. to Nov.	Oct. to Nov.	Mean body weight (kg)	60.0	52.0	8.0	13.3
F	October	November	Mean hooking rate (%)	5.99	1.49	4.50	75.1
	"	"	Catch-quantity (kg)	409.40	77.48	331.92	81.1
	November	November	Mean hooking rate	7.10	2.70	4.40	62.0
	"	"	Catch-quantity	426.00	140.40	285.60	67.0
H	October	November	Mean hooking rate	7.90	5.51	2.39	30.3
	"	"	Catch-quantity	474.00	286.52	187.48	39.6

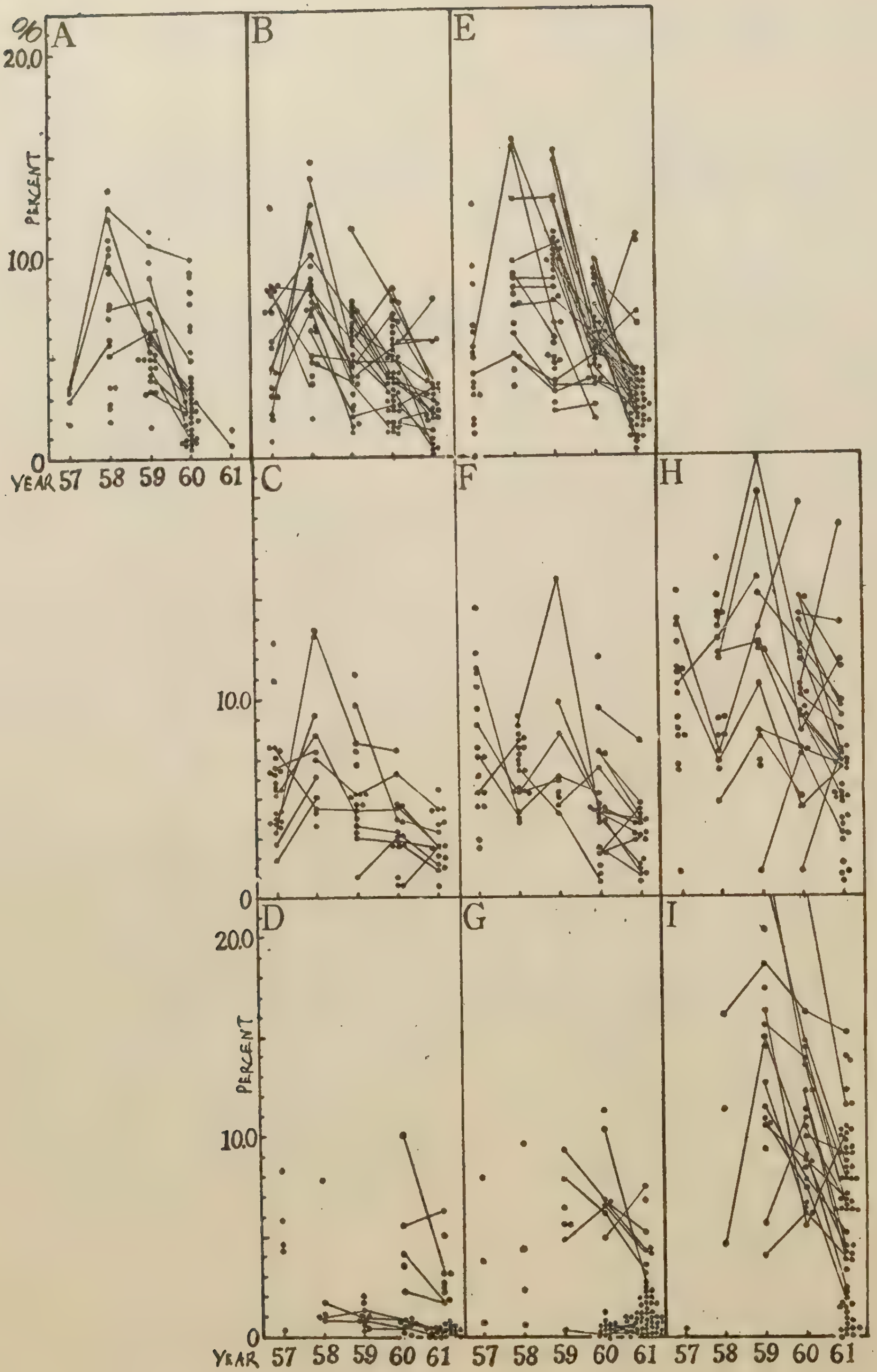

Fig. 7 Annual variation in hooking-rate of yellowfin tuna by sub-area.

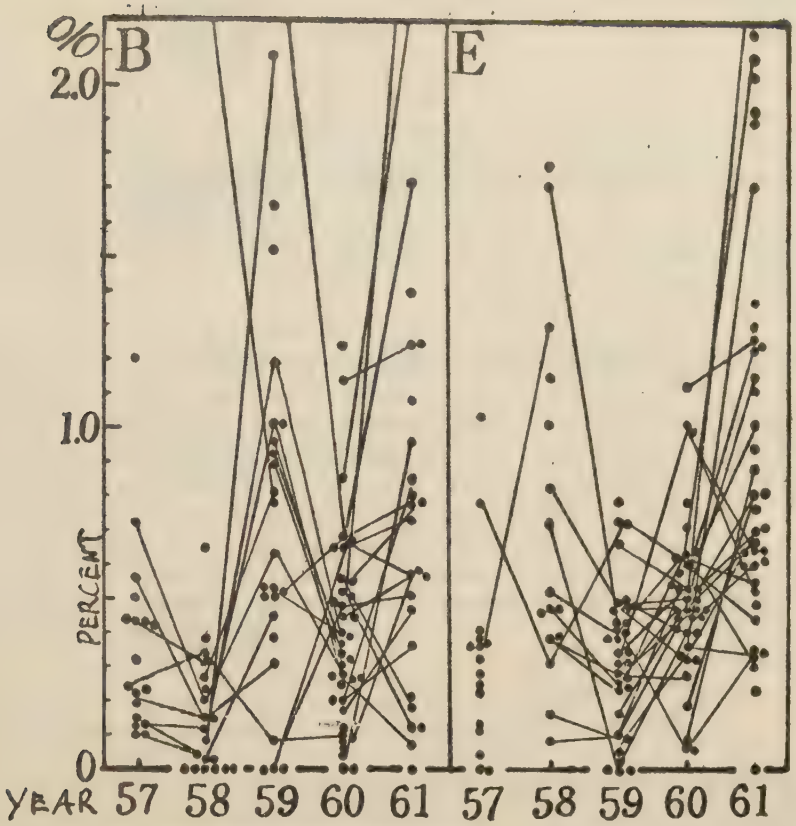

Fig. 8 Annual variation in hooking-rate of bigeye tuna by sub-area.

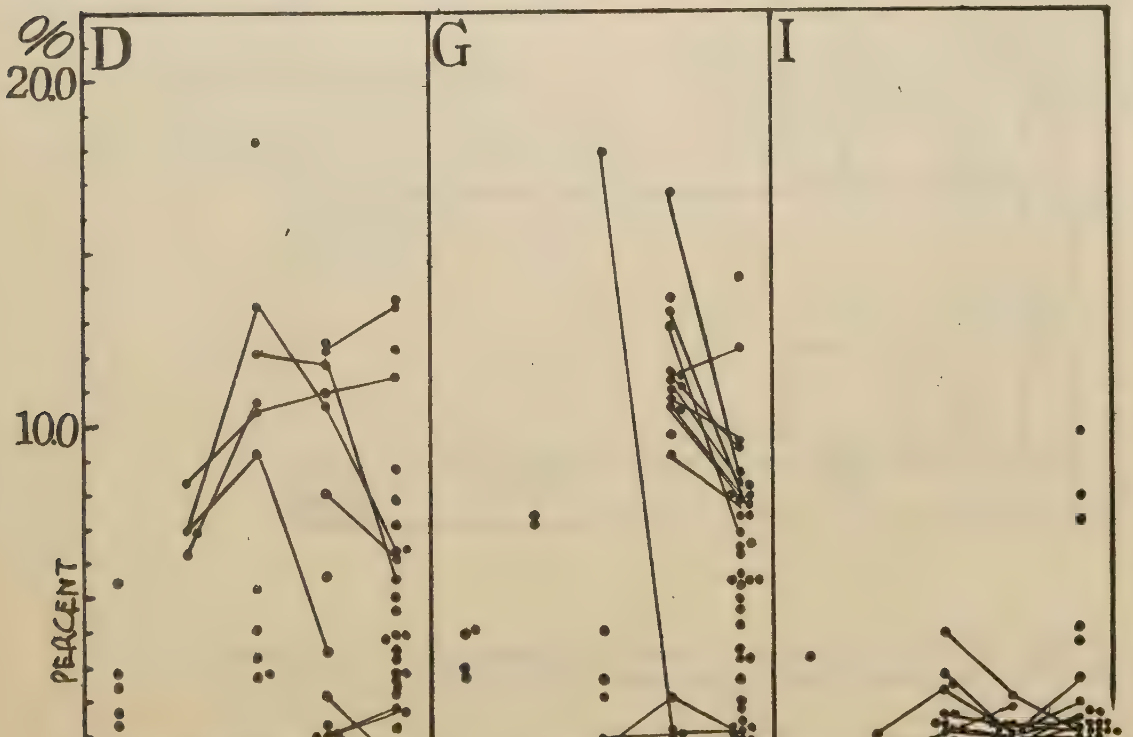

Fig. 9 Annual variation in hooking-rate of albacore by sub-area.

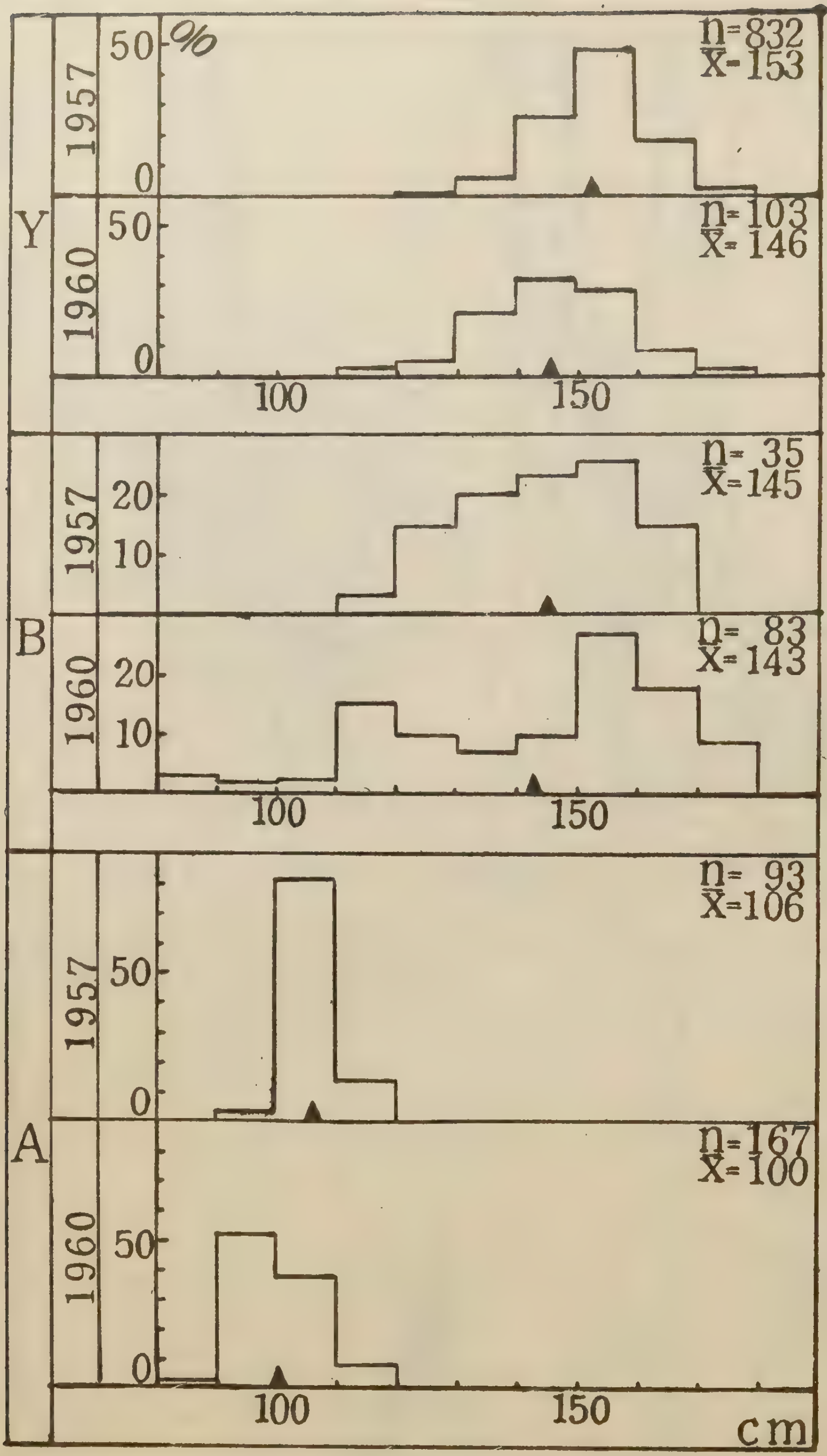

Fig. 10 Length frequency and mean fork length of yellowfin tuna, bigeye tuna and albacore captured by longline in the Atlantic Ocean, 1957 to 1960.

Y = Yellowfin tuna
B = Bigeye tuna
A = Albacore

A uniform condition in respect to bigeye tuna occurs in all the large sub-areas; that is, the good fishing season starts in May and ends in October, though the fishing declines somewhat in July, and the poor fishing season lasts from December to March.

In large sub-areas A, B and E the good fishing season for albacore starts in October and ends in November, and another good season opens in March and closes in May, while the poor fishing season lasts from July to September; the condition from December to February is unknown. In large sub-areas C, F and H the good fishing season opens in May and ends in September for albacore. The large sub-areas D, G and I have a good season for albacore in November to March and an off-season in May to September.

Blue marlin has two good fishing seasons and two poor seasons in each year in large sub-areas A, B, C, E, F and H: the good seasons last from March to June and from September to November and the poor seasons from July to August and from December to February. In large sub-areas D and G the good fishing season opens in November and ends in April and the poor season lasts from June to September.

6.2 Annual variation of hooking-rate

The hooking-rate for yellowfin tuna has been declining since 1958 in large sub-areas A, B, C and E, and since 1959 in large sub-areas D, F, G, H and I.

In sub-area B, the hooking-rate for bigeye tuna showed a variation by alternate years, that is, the rate was high in odd years and low in even years. In sub-area E, the hooking-rate was high in 1958 and 1961 and low in 1957, 1959 and 1960.

In sub-areas D, G and I, which represent the main fishing ground for albacore, the hooking-rate of this fish has been gradually declining since 1959.

6.3 Annual variation of catch-quantity per 100 hooks

The mode and the mean fork length of both yellowfin tuna and albacore were less in 1960 than in 1957.

The mode in the fork length of a group of bigeye tuna, which stood at 140-160 cm in 1957 (Fig.10), consisted of two modes in 1960, one at 110-120 cm and the other at 150-170 cm.

It is concluded that the annual variation of the catch-quantity of yellowfin tuna per unit of operation (100 hooks) has been decreasing as the result of a decline in hooking-rate and a decrease in fork length.

Experience Paper No. 17

DISTRIBUTION OF THE YELLOWFIN TUNA *Neothunnus macropterus* (Temminck and Schlegel) IN THE TUNA LONGLINE FISHING GROUNDS OF THE PACIFIC OCEAN

By

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Abstract

Knowledge of the distribution of yellowfin tuna in the western and central equatorial Pacific has been greatly advanced in recent years as a result of expanded operations of Japanese longline vessels and by investigations of the U. S. Bureau of Commercial Fisheries. The longline hooking-rate attains a maximum near the Equator, in the western and central Pacific, and decreases toward higher latitudes. The latitude of maximum catch shifts northward in a west-to-east direction. In the eastern Pacific, perhaps because of a tongue of cold water, the yellowfin are less abundant immediately on the Equator than to the north and south.

The yellowfin occurs principally in the South Equatorial Current, while the bigeye is most abundant in the North Equatorial Current, suggesting environmental differences to which the tunas are sensitive. Temperature does not seem to be a controlling factor.

The distribution of yellowfin exhibits only small seasonal variations in the equatorial region. Seasonal peaks show in the catch at higher latitudes, however, in the western Pacific, and also in the eastern Pacific depending on the strength of the tongue of cold water on the Equator.

There is a west-east gradient of increasing size of yellowfin across the Pacific. Young yellowfin are more likely to occur in high densities near islands or near land than in the open ocean. A study is now in progress to determine the effect of exploitation on the size composition of the yellowfin population.

The authors believe that the yellowfin population of the equatorial Pacific consists neither of a single, well-mixed homogeneous population nor of two or more highly independent groups, but is represented by a state intermediate between the two.

DISTRIBUTION DU THON A NAGEOIRES JAUNES *Neothunnus macropterus* (Temminck et Schlegel) DANS LES LIEUX DE PECHE DU THON AUX PALANGRES DU PACIFIQUE

Résumé

Ces dernières années, le développement des opérations des thoniers-palangriers japonais et les enquêtes menées par le Bureau of Commercial Fisheries des Etats-Unis d'Amérique ont fait faire de grands progrès aux connaissances sur la distribution des thons à nageoires jaunes dans les parties occidentale et centrale du Pacifique équatorial. Le taux de capture aux palangres est maximal près de l'Equateur dans le Pacifique Ouest et central et décroît à mesure que s'élève la latitude. La latitude correspondant aux prises maximales se déplace vers le nord, d'ouest en est. Dans le Pacifique Est, peut-être en raison de l'existence d'une langue d'eau froide, les thons à nageoires jaunes sont moins abondants sur l'Equateur même qu'au nord et au sud de celui-ci.

Le thon à nageoires jaunes fréquente surtout la zone intéressée par le courant sud-équatorial, tandis que le thon obèse est très abondant dans celle du courant nord-équatorial, ce qui suggère des différences de milieu auxquelles les thons seraient sensibles. La température ne paraît pas jouer un rôle déterminant.

La distribution du thon à nageoires jaunes ne manifeste dans la région équatoriale que de faibles variations saisonnières. A des latitudes plus élevées, toutefois, les captures révèlent des maximums saisonniers dans le Pacifique Ouest, ainsi que dans le Pacifique Est, selon l'importance de la langue d'eau froide à l'Equateur.

Dans le Pacifique, la taille des thons à nageoires jaunes s'accroît progressivement à mesure que l'on va d'ouest en est. Les fortes concentrations de jeunes individus se trouvent plus fréquemment près des îles ou des côtes qu'en pleine mer. Une étude est en cours pour déterminer l'effet de l'exploitation sur la composition par taille de la population de thons à nageoires jaunes.

Les auteurs de la communication sont d'avis que la population de thons à nageoires jaunes du Pacifique équatorial ne consiste ni en une seule population homogène, ni en deux ou plus de deux groupes nettement différenciés, mais qu'elle est représentée par un stade intermédiaire.

LA DISTRIBUCION DEL ATUN DE ALETA AMARILLA. *Neothunnus macropterus* (Temminck y Schlegel) EN LOS CALADEROS DEL PACIFICO PARA LA PESCA CON PALANGRE

Extracto

Los conocimientos acerca de la distribución del atún de aleta amarilla en las zonas oeste y central del Pacífico ecuatorial han adelantado muchísimo estos últimos años gracias a la expansión de las operaciones por los palangreros japoneses y a las investigaciones de la Oficina estadounidense de Pesquerías Comerciales. El ritmo de las capturas con palangre alcanza su punto máximo cerca del Ecuador, en el Pacífico central y occidental, y disminuye hacia las mayores latitudes. La latitud donde se obtienen capturas máximas se desplaza hacia el Norte, en dirección O-E. En el Pacífico oriental, debido, quizás, a una lengua de agua fría, el atún de aleta amarilla es menos abundante en las inmediaciones del Ecuador que en el Norte y el Sur.

El atún de aleta amarilla se presenta principalmente en la corriente sudecuatorial, mientras que el obeso o patudo abunda muchísimo en la norecuatorial, lo cual sugiere diferencias ambientales a las que son sensibles los atunes. No parece que la temperatura sea un factor determinante.

La distribución del atún de aleta amarilla presenta sólo escasas variaciones estacionales en la región ecuatorial. Sin embargo, las capturas efectuadas en mayores latitudes del Pacífico occidental muestran máximas estacionales, así como también las del Pacífico oriental, según la intensidad de la lengua ecuatorial de agua fría.

En todo el Pacífico se observa que el atún de aleta amarilla aumenta de talla en la dirección O-E. Con mayores probabilidades, los ejemplares jóvenes aparecen en cardúmenes más densos junto a las islas o cerca de la costa que en aguas despejadas. Actualmente, está en marcha un estudio para determinar los efectos de la explotación sobre la composición de la población por tamaños.

Los autores opinan que la población de atunes de aleta amarilla del Pacífico ecuatorial no constituye un conjunto homogéneo de un solo tipo ni dos o más grupos muy independientes, sino que está representada por un estado intermedio.

1. INTRODUCTION

Our knowledge of the distribution of yellowfin tuna in the western and central Pacific Ocean has been markedly advanced in recent years as a result of expanded operations of Japanese longline vessels and by investigations conducted by POFI,[1] and a considerable number of works has been published dealing with this subject. These works deal with different sea regions individually, but cover, as a whole, the entire extent of the currently exploited tuna longline fishing ground of the Pacific. This fishing ground extends over the western, central and a part of the eastern Pacific and includes the tropical and the northern and southern temperate zones. The subjects of these works range from quantitative descriptions of the distribution of the yellowfin to such various topics as migration, relationship between the distribution and the environment, and others.

In the present study some important questions concerning the principal features of the distribution of the yellowfin in this area are considered on the basis of the results of these previous works augmented with some original data. In addition, there is some discussion of the population structure of the yellowfin occurring in these fishing grounds.

The writers express their sincere thanks to Dr. Kiroshi Nakamura, Director, and Dr. Hiroshi Yabe, Chief of the Oceanic Resources Section, the Nankai Regional Fisheries Research Laboratory, for the encouragement and guidance given them during the preparation of this paper and for critically reviewing the manuscript. They also thank Dr. Yoichi Yabuta of the same Laboratory for valuable advice, and Assistant Professor Haruyuki Koyama, Hiroshima University, for translating the text into English.

2 GENERAL FEATURES OF DISTRIBUTION

The tuna longline is the major gear with which Japanese fishermen catch yellowfin tuna. Pole-and-line, trolling jigs, purse seines, set nets, etc. are also used by Japanese to catch yellowfin, but these gears, with the exception of pole-and-line, are used only in the waters closely adjacent to the Japanese homeland. Pole-and-line fishing for tunas is practiced in Japanese coastal waters and the contiguous open-sea regions, but rarely south of the parallel 20°N or east of the meridian 160°E. The waters exploited by this fishery are, therefore, much smaller in area than those exploited by the longline fishery, and situated far from the center of the distribution of the yellowfin. Under these circumstances, our knowledge of the distribution of the yellowfin in the western and central Pacific, including the findings made by POFI in their investigations, is based almost exclusively on the results of longline operations conducted for commercial or other purposes. The longline, however, exerts characteristic size selectivity. As is illustrated in Fig. 1, the yellowfin caught by longline are composed mainly of large and medium-sized fish above 100 cm in body length, whereas those taken by pole-and-line are almost exclusively small fish below 100 cm. This marked difference in size composition between the catches of the two fishing methods clearly indicates that the longline is situated for catching large and medium-sizedfish and therefore takes the fish of such sizes selectively. It then follows that any information that can be derived from the results of longline operations should pertain chiefly to relatively old fish. This is an important limitation inherent in the information derived from longline fishing.

On the other hand, records of commercial longline operations offer a great advantage since they cover the waters where yellowfin are sparse, as well as where they are abundant. This is due to the fact that these boats fish not only for yellowfin but also for other species of tunas and spearfishes. In the Pacific Ocean, tuna longline boats now range from about lat.40°N southward across the Equator to about

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[1] Pacific Oceanic Fishery Investigations. Currently: U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii

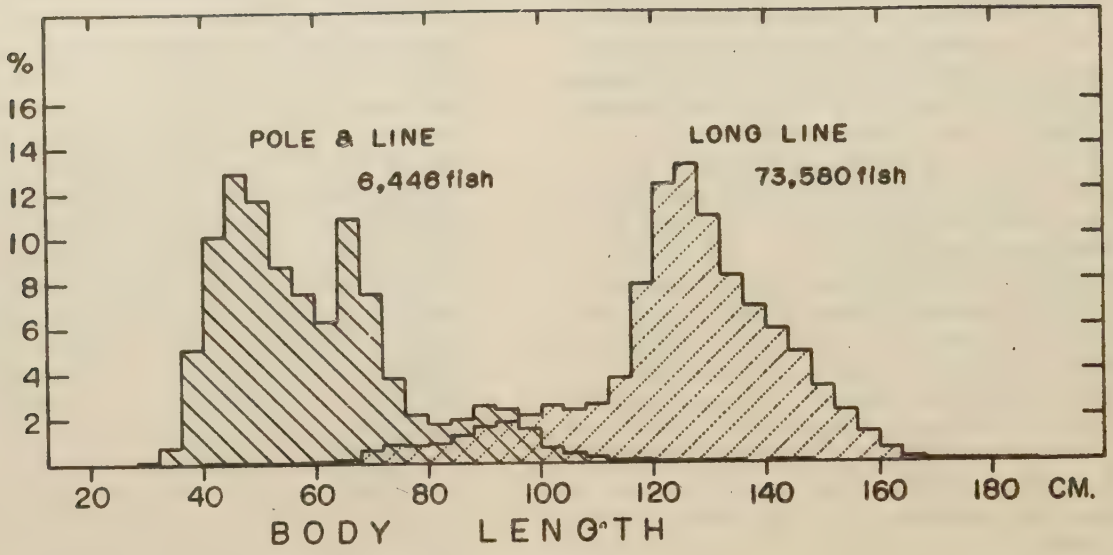

Fig. 1 Comparison of size composition of yellowfin caught by longline and by pole-and-line fishing (based on data from April 1954 through March 1955)

lat. 40°S, and from the Asian coast eastward to about long. 100°W (Fig. 2). Although catches of yellowfin have been reported from practically every part of this extensive area, the abundance of this species to the north of 25°N and south of 30°S is too low to deserve consideration from an economic viewpoint. It is the tropical waters on both sides of the Equator that constitute the main fishing ground of yellowfin. Apart from this latitudinal variation, there is a tendency for densities of yellowfin to be higher near the western extreme of the fishing ground (i.e., in the vicinity of the Philippine Islands and the Australian continent) than in the open ocean to the east. Off the coast of Australia, in particular, the yellowfin are sufficiently abundant to support a longline fishery with this species as the principal object.

Thus, in the Pacific Ocean, the yellowfin occurs in both the northern and southern hemispheres including the equatorial belt. We shall now examine the distribution of this fish over the above-mentioned range of occurrence, with special reference to geographic variations in its density.

Fig. 3 shows the geographic variation in the hooking-rate[1] of yellowfin in the longline fishing grounds in the western and central Pacific between long. 150°E and 150°W; the hooking-rates are calculated for rectangles bounded by 2 degrees of latitude and 10 degrees of longitude.

It is indicated in Fig. 3 that, in each longitudinal zone bounded by 10 degrees of longitude, the hooking-rate attains the maximum in the vicinity of the Equator and decreases toward higher latitudes. This decrease, however, does not occur in the same manner in the northern and southern hemispheres;in the former, the decrease is sharp so that the hooking-rate approaches zero within a relatively short distance from the Equator; in the latter, the hooking-rate decreases gradually over a long distance from the Equator. This asymmetric decrease of hooking-rate on the two sides of the Equator indicates that the distribution of yellowfin in the central and western Pacific is not centered on the Equator but is displaced to the south.

Comparison of the hooking-rates at corresponding latitudes among the longitudinal zones indicates that catches at the same latitude did not differ greatly among the five longitudinal zones east of long. 160°W. However, the maximum hooking-rate does not occur at the same latitude in each zone. It occurs south of the Equator to the west of the 180° meridian, but north of the Equator to the east of long. 170°W, indicating that the latitude of the maximum catch shifts progressively northward from west to east. This shift has been pointed out by Murphy and Shomura (1953b), Yabuta and Yukinawa (1959), and Kamimura and Honma (1959). According to Yabuta and Yukinawa, the latitude of the hooking-rate maximum varies not only with the longitude, as just mentioned, but to a certain extent with the season of the year. The longitudinal zone bounded by the meridians of 150°E and 160°E is distinguished from the foregoing five zones, by the considerably high hooking-rates in southern latitudes. These latitudes occur in the waters off Australia where, as stated before, the density of yellowfin is higher than in the open ocean.

The distribution of yellowfin in the equatorial region of the eastern Pacific does not conform to the pattern encountered at the latitudes in the western and central Pacific. Whereas densities of fish are highest about the Equator in the western and central regions in the eastern Pacific along the Equator there is a belt of low yellowfin density, as shown in Fig. 10. This decrease in yellowfin abundance, which is barely discernible near long. 150°W, becomes increasingly pronounced toward the east. Near the eastern extreme of the fishing ground, the area of high yellowfin density bifurcates into a northern and a southern branch, which lie on the respective sides of the Equator. Apart from this difference, it has been suggested that yellowfin are probably somewhat sparser in these waters than in the equatorial region of the central and western Pacific (Murphy and Shomura 1955; King and Hida 1957), but further discussion of this matter must be postponed until additional data are accumulated.

The over-all picture of the distribution of yellowfin in the Pacific longline fishing grounds indicatesthat the density of the fish does not show any break or abrupt change either in a

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[1] The hooking-rate, as used here, is the number of fish caught per hook of the longline, as a percentage, and the equivalent of the unit "catch per hundred hooks".

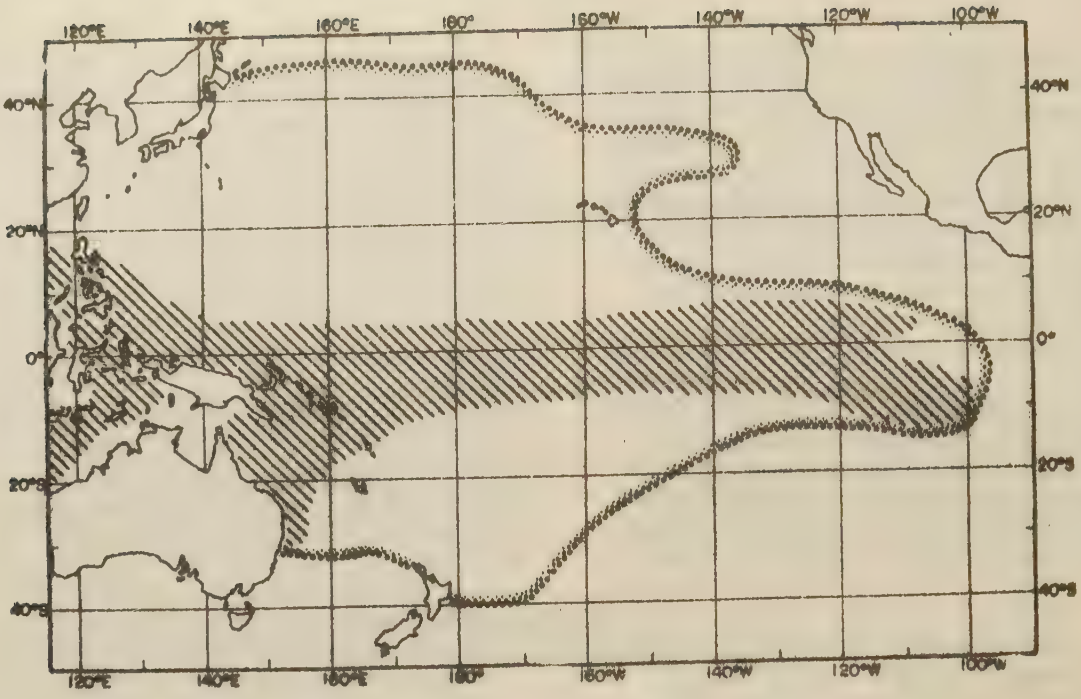
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
40°N
20°N
0°
20°S
40°S

Fig. 2 Extent of tuna longline fishing grounds (dotted) and the area of dense distribution of yellowfin (hatched) in the Pacific Ocean

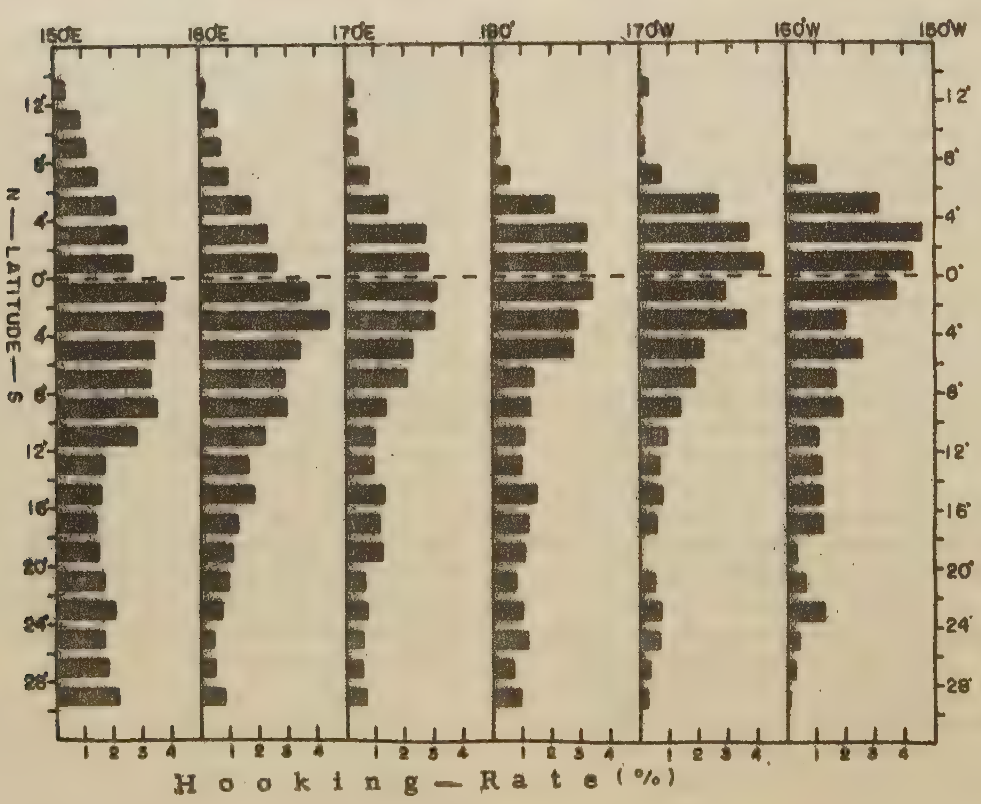

Fig. 3 Hooking-rate of yellowfin in the Western and Central Pacific

Hooking-rates are based on the data for all seasons combined. This diagram can be regarded as representing a condition similar to the annual average condition.

north-south or an east-west direction. In certain localities there are very complicated local variations, however. This distribution pattern may be regarded as the outstanding characteristic of the distribution of the yellowfin, and in contrast to the distribution of the albacore and bigeye, which are distinguishable into two or more populations each of which has an area of maximal density in the center (Suda, Tatsuki and Uto 1959).

3 DISTRIBUTION IN RELATION TO ENVIRONMENT

Nakamura (1954) studied the distribution of tunas and spearfishes in relation to the location of ocean currents in the Pacific longline fishing ground and found that the position of the center of the distribution of each species (or growth stage of a species) was closely correlated to a certain current or current system which differed according to the species (or growth stage of a species). He hypothesized, on the basis of this finding, that each current or current system provides a habitat for tunas and spearfishes that differs in character from that provided by another current or current system. It may be that this type of correlation is of universal occurrence, because it has been shown that the distribution of tunas in the Indian ocean (Mimura and Nakamura 1959) and the Atlantic Ocean (Nakamura and Kamimura 1958) are also similarly correlated to ocean currents.

Correlation between the distribution of the Pacific yellowfin and the ocean currents is explained with the aid of Figs. 4 and 5. In Fig. 4 the latitudinal variations in the density of the yellowfin are compared with those of the bigeye for three longitudinal zones in the western and central Pacific. The bigeye has been chosen for the comparison, because its habits simulate that of the yellowfin more closely than those of other tunas do. This figure clearly indicates that the distributions of the two tunas differ markedly in many respects, including the position of the area of maximal densities. If Fig. 4 is contrasted with Fig. 5, which shows the current pattern of the same region, it is apparent that the yellowfin occurs mostly in the region of the South Equatorial Current and the bigeye mostly in the region of the North Equatorial Counter Current, and that these two regions are separated by the Equatorial Current. This fact suggests that the environment of the tunas is not the same in the North and the South Equatorial Currents, and that the yellowfin is better adapted to the environment characteristic of the latter current. Concentration of yellowfin in the South Equatorial Current accounts for the fact that, in the western and central Pacific, this fish occurs in higher densities and at higher latitudes to the south of the Equator than to the north of the Equator.

So far, little is known concerning the factors and processes which give rise to this relation between the distribution of tunas and the ocean currents. Recently, such concepts as the ocean structure and the water mass have been introduced by Nakamura and Yamanaka (1959) and Yamanaka and Anraku (1959, 1961), for a better understanding of this correlation.

There is also a series of works in which the distribution of the Pacific yellowfin has been studied in relation to food supply. Cromwell (1953) and Murphy and Shomura (1953a, 1953b, 1955) have pointed out that there is a correspondence between the concentration of yellowfin and the upwelling that occurs along the Equator in the central Pacific, and explained this correspondence as follows: Increased abundance of plankton, due to the enrichment of the euphotic zone by the admixture of nutrient-rich deep water drawn up by upwelling, causes the aggregation of fishes of successively higher trophic levels culminating in the tunas. From this viewpoint, Cromwell considered the occurrence of upwelling and the drift of upwelled water in relation to the southeast trade wind prevailing in this area, and discussed the possibility that the zone of rich plankton crop should be displaced north of the Equator.

Meanwhile, Murphy and Shomura (1953b) recognized that the yellowfin are encountered in greatest abundances in more and more southerly latitudes as one moves from east to west in the central and western Pacific (i.e., the shifting tendency which has been referred to in the preceding chapter) and inferred that the shift of the prevailing trade wind from southeast to northeast might have some bearing on this phenomenon. Subsequently, Sette (1955), Fig. 6, systematized these inferences made by the aforementioned authors into a theory, which holds that the oceanic circulatory system, including upwelling, is the major factor which determines the geographic variation in the abundance of tunas in the tropical and subtropical waters. The distribution of zooplankton volume in the equatorial region of the central Pacific

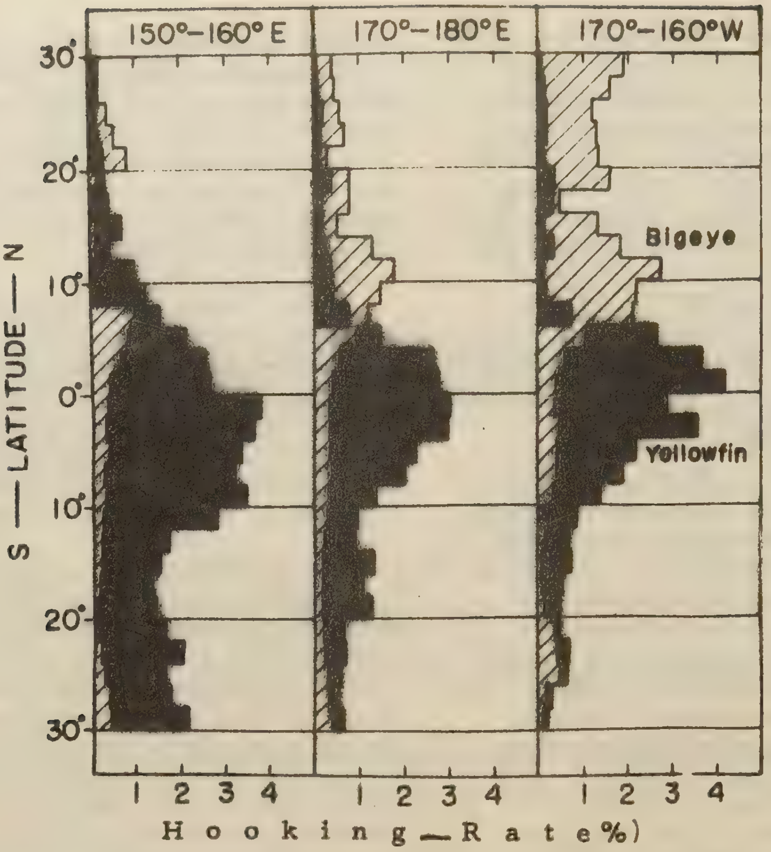

Fig. 4 Comparison of hooking-rates of yellowfin (black) and bigeye (hatched) in three longitudinal zones of the western and central Pacific.

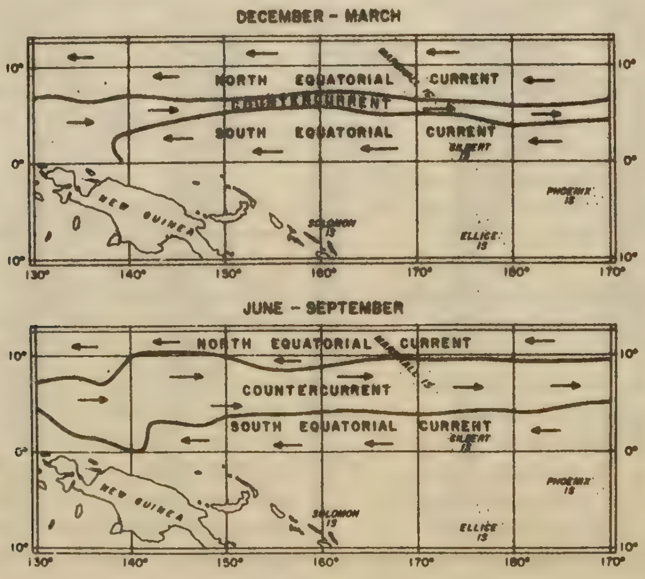
DECEMBER - MARCH
NORTH EQUATORIAL CURRENT
COUNTERCURRENT
SOUTH EQUATORIAL CURRENT
MARSHALL IS
GILBERT IS
PHOENIX IS
NEW GUINEA
SOLOMON IS
ELLICE IS
10°
0°
10°
130° 140° 150° 160° 170° 180° 170°
JUNE - SEPTEMBER
NORTH EQUATORIAL CURRENT
COUNTERCURRENT
SOUTH EQUATORIAL CURRENT
MARSHALL IS
GILBERT IS
PHOENIX IS
NEW GUINEA
SOLOMON IS
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Fig. 5 Location of the major currents in the western and central Pacific (after Murphy and Otsu (1954))

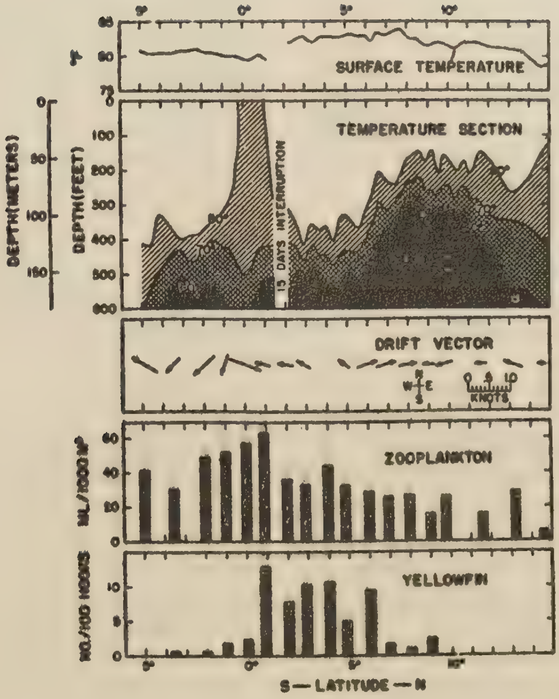

Fig. 6 Surface temperature, vertical temperature field, longline drift, zooplankton abundance in the upper 200 m, and the yellowfin catch along long. 150°W, August 22 to September 25, 1951 (after Sette 1955)

as studied by King and Hida (1957), verified Sette's hypothesis as far as the distribution of the yellowfin is concerned, but failed to do so in the case of the distribution of the bigeye (Fig. 7). King and Ikehara (1956), who studied the feeding habits of the yellowfin and the bigeye comparatively, stated that they could not find any fact that might account for the separated distribution of the two species. Furthermore, as will be described later, there is an indication that upwelling is responsible for the low abundance of yellowfin along the Equator in the eastern Pacific. Thus, it does not seem that Sette's hypothesis is valid for all the tropical and subtropical waters, although it applies to the situation prevailing in the equatorial region of the central Pacific.

The hypotheses proposed by Nakamura and by Sette considerably differ from each other in the way of thinking and in applicability, but both of them attach little importance to a direct relationship between the distribution of tunas and water temperature. Nakamura (1951) stated as follows concerning the relationship between the distribution of tunas and water temperature: Near the extremes of the geographic range of a species, temperature can be the 'limiting factor' of the fishing ground and fishing season for that species. But it seems improbable that formation of a fishing ground or fishing season is principally controlled by temperature in those waters where temperatures favorable to the species persist all the time. Sette also expressed a similar view with regard to the distribution of the yellowfin in the equatorial central Pacific. Thus, no special significance has been attached to temperature as a factor controlling the distribution of the yellowfin in the equatorial region of the western and central Pacific.

In contrast, in the same region of the eastern Pacific, there is a good correspondence between the distribution of yellowfin and a belt or tongue of cold water lying on or nearly parallel to the Equator (Fig. 10). The area and strength of this cold water belt vary with the season, accompanied by marked seasonal changes in the distribution of the yellowfin in these waters. In addition, Yabuta and Yukinawa (1959) recognized that the area of maximal abundance of the yellowfin is not separated so distinctly from that of the bigeye in these longitudes as in the western and central Pacific. It has also been indicated that there is a marked discrepancy between the distributions of zooplankton volume and of yellowfin in these longitudes (King and Hida 1957). Though the oceanography of this cold water belt or tongue is not well understood, Yamanaka and Anraku (manuscript) have found that it is characterized by a specific water type, and express the opinion that water type should be taken into account, as well as temperature, in analyzing the apparent correlation between this cold water and the distribution of tunas. At any rate, the fact that oceanographic conditions of the equatorial region of the eastern Pacific are markedly different than those in the central and western Pacific seems to be one of the important points which should be taken into account in studying the distribution of the yellowfin over the equatorial waters of the Pacific in relation to the environment.

4 SEASONAL VARIATION

Generally speaking, the distribution of yellowfin exhibits only small seasonal variations in the Pacific longline fishing grounds. In the course of a year, no remarkable change occurs in the location of abundance maxima or in abundance gradients in a north-south and east-west direction (Figs. 11-14). In general, seasonal variations are indistinct in low latitudes, and become more and more conspicuous toward higher latitudes. The previous works on the seasonal variation of the distribution of the Pacific yellowfin, on which the foregoing generalization is based, are briefly reviewed below.

Nakamura (1951) indicated that the hooking-rate of the yellowfin reaches a maximum twice a year (i.e. about May to July and about November to December), in the Bonin Islands waters and inferred that the maxima are caused by the seasonal movements of the fish which is directed toward the north from about spring to summer and toward the south from about autumn to winter. The presence of these seasonal movementsof fish, very similar to those presumed by Nakamura, was recognized by Yabuta and Yukinawa (1954) and Ueyanagi and Watanabe (1959). According to Moore (1951) the peak of the yellowfin fishery occurs in summer in Hawaiian waters. On the other hand Kamimura and Homma (1959) showed that two peaks of hooking-rate occur annually (i.e., in December-March and in May-June), in the region between latitudes 10°S and 20°S of the western and central South Pacific, and attributed the first peak to a southward movement of fish taking place from spring to summer and the second peak to a northward movement occurring from autumn to winter (Fi 8).

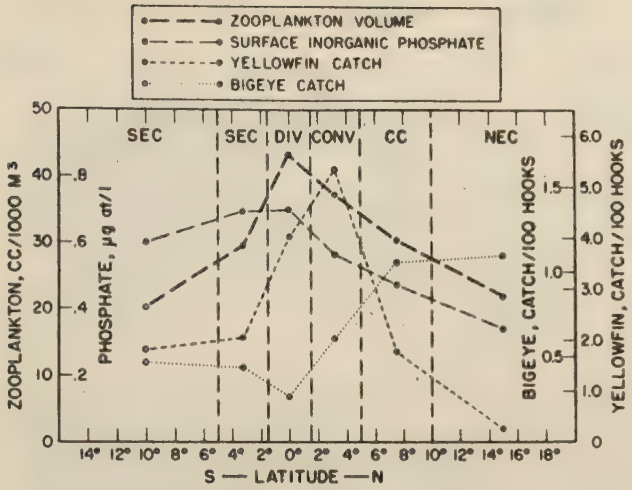

Fig. 7 Variations with the current system in yellowfin and bigeye catch on longline gear, zooplankton volumes (adjusted) and surface inorganic phosphate for the range of longitude 120°W to 180° (after King and Hida (1957))

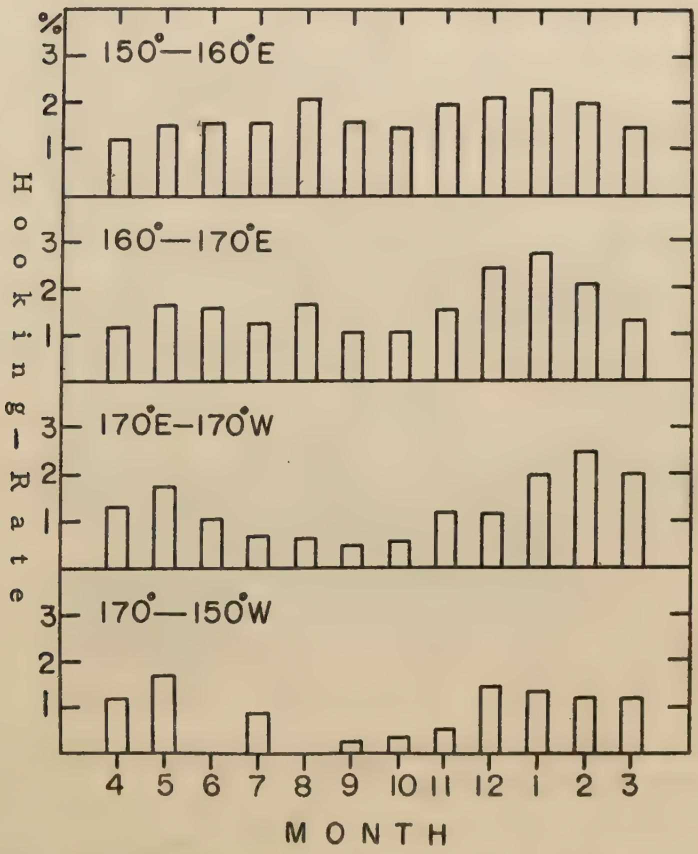

Fig. 8 Seasonal variation in the hooking-rate of yellowfin in the western and central Pacific between latitudes 10°S and 20°S (after Kamimura and Honma (1959)).

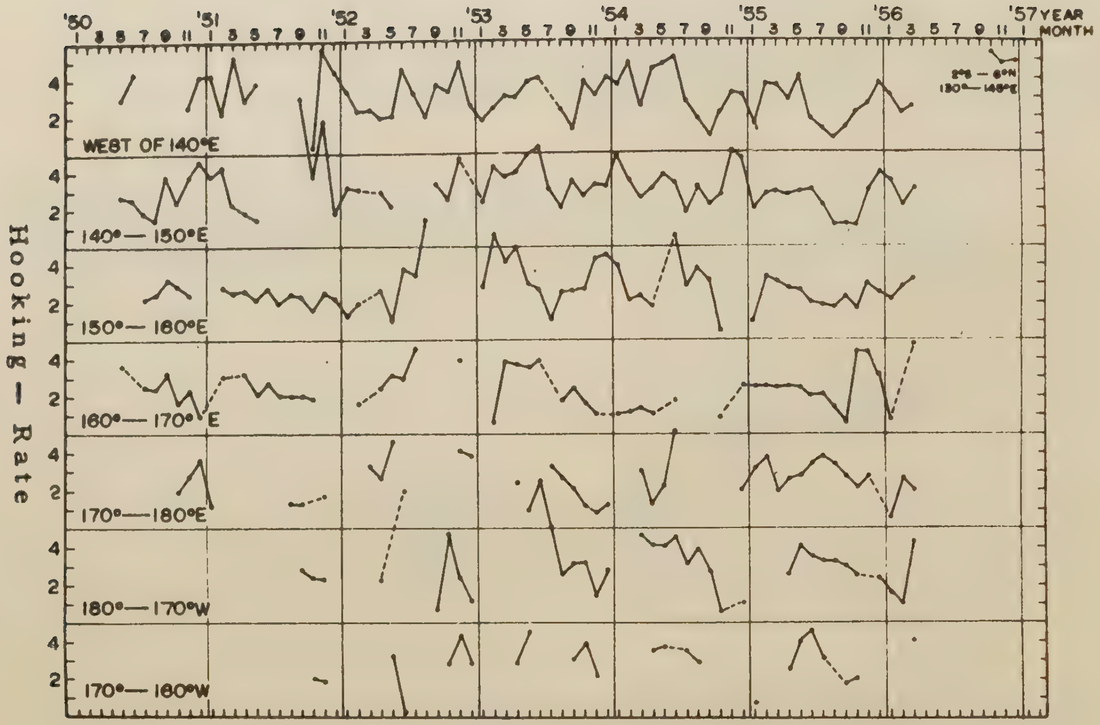

Fig. 9 Fluctuation of monthly hooking-rate of yellowfin in the equatorial region (lat. 2°S - 6°N) of the western and central Pacific from 1950 through 1957 (after Yabuta and Yukinawa 1959)

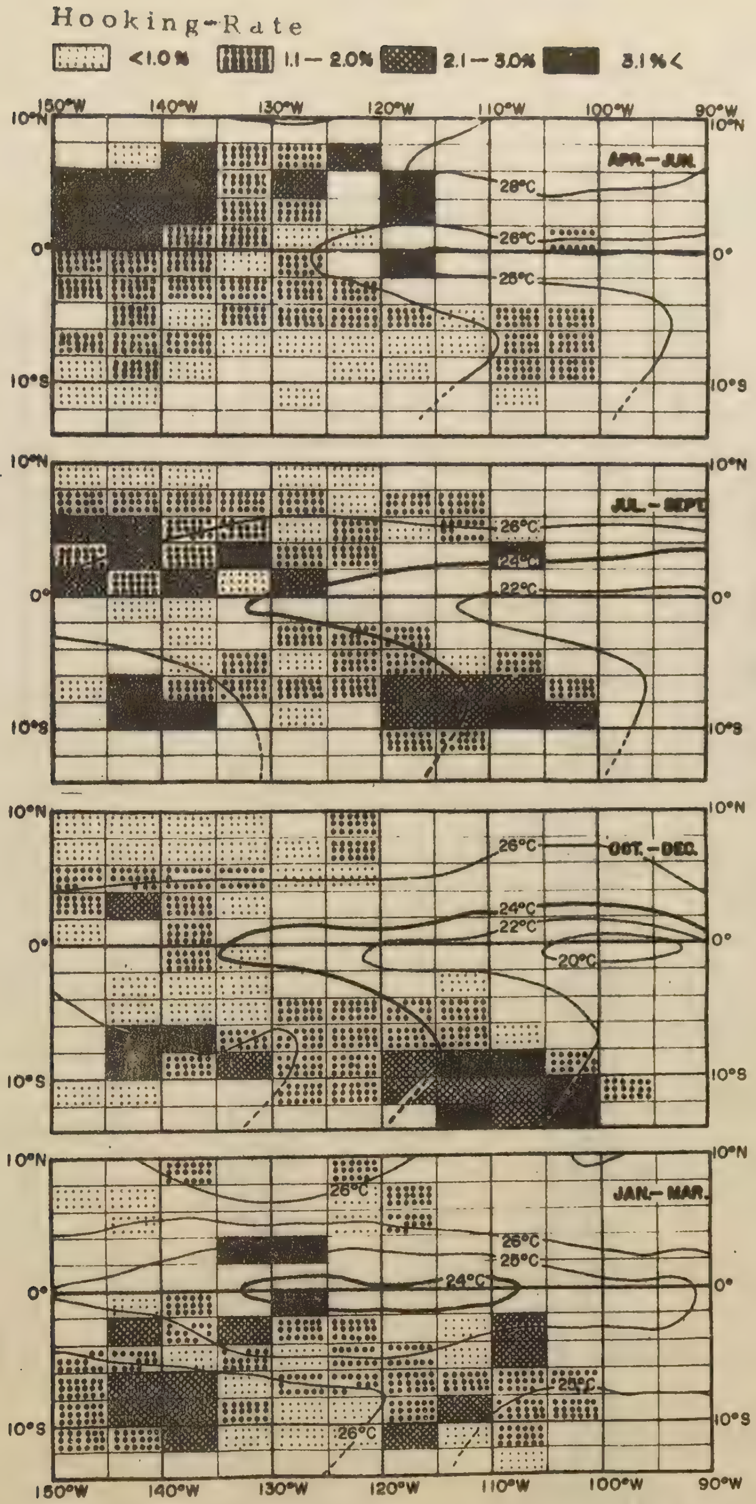
Hooking-Rate
<1.0%
1.1 – 2.0%
2.1 – 3.0%
3.1%<
150°W
140°W
130°W
120°W
110°W
100°W
90°W
10°N
0°
10°S
APR.–JUN.
28°C
26°C
25°C
JUL.–SEPT.
26°C
24°C
22°C
OCT.–DEC.
26°C
24°C
22°C
20°C
JAN.–MAR.
26°C
26°C
28°C
24°C
25°C
26°C

Fig. 10 Distribution of yellowfin hooking-rate and surface temperature in the eastern part of the Pacific tuna longline fishing ground by seasons

Hooking-rates are based on data from January 1958 through December 1960. Distribution of surface temperature is redrawn from "Current Chart of the Northern Pacific" published by the Japanese Hydrographic Office in 1936.

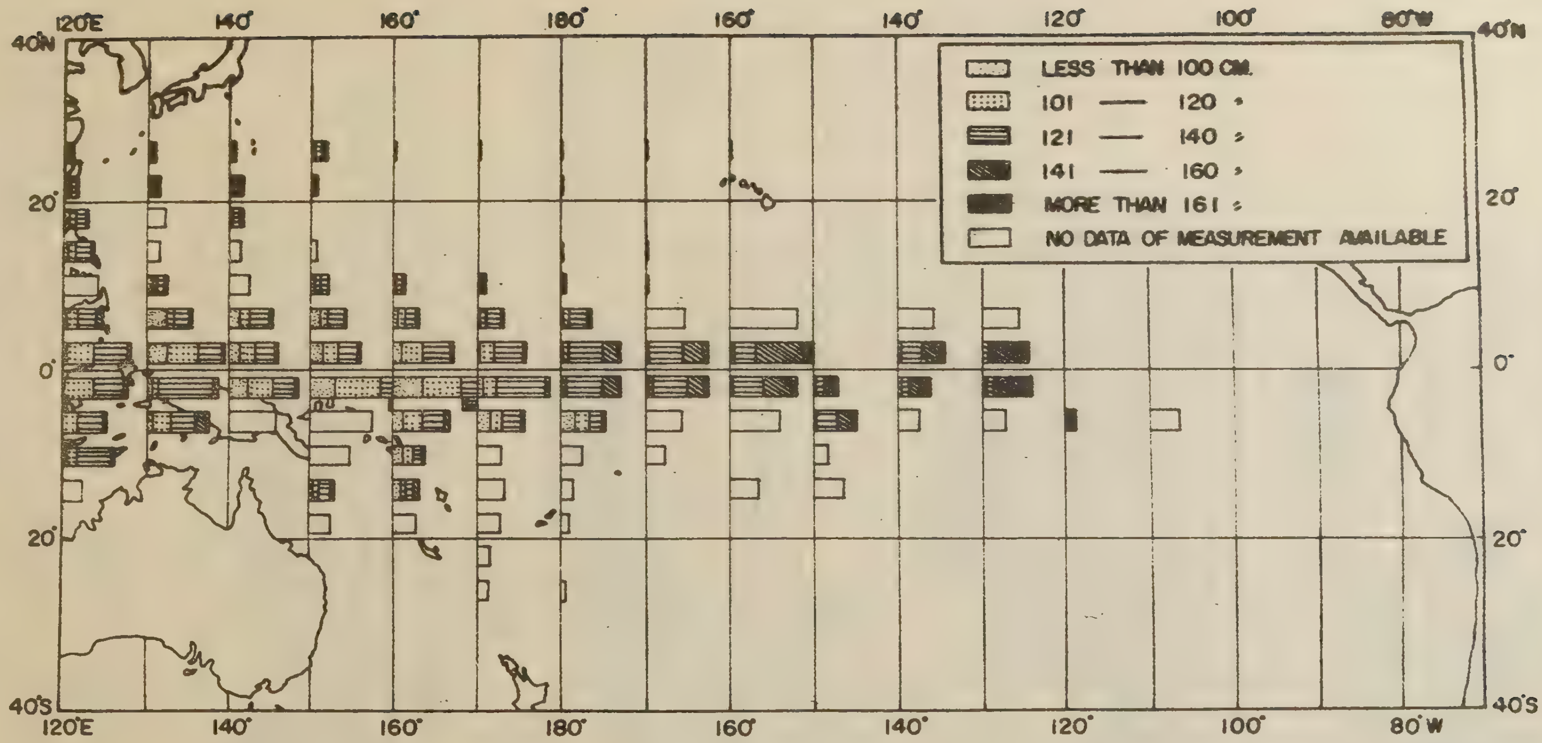
120°E
140°
160°
180°
160°
140°
120°
100°
80°W
40°N
20°
0°
20°
40°S
▨ LESS THAN 100 CM.
▨ 101 —— 120 〃
▤ 121 —— 140 〃
▨ 141 —— 160 〃
■ MORE THAN 161 〃
☐ NO DATA OF MEASUREMENT AVAILABLE

Fig. 11 Distribution of hooking-rate of yellowfin of various size classes in the Pacific Ocean: April to June

Scale of histogram: 10 degrees of longitude correspond to 5% of hooking-rate.

(See footnote 3/ of text for explanation.)

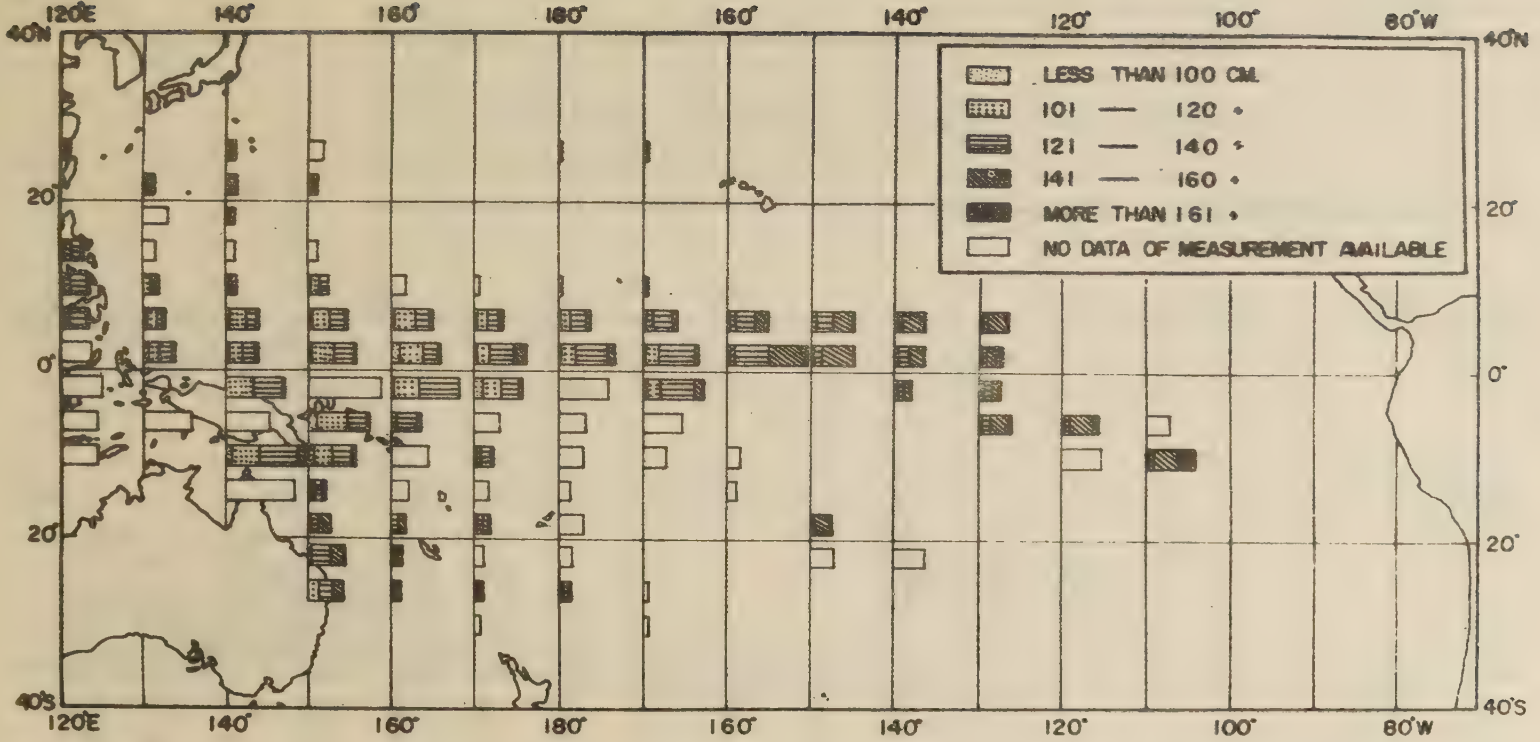
120°E
140°
160°
180°
160°
140°
120°
100°
80°W
40°N
20°
0°
20°
40°S
LESS THAN 100 CM.
101 — 120 "
121 — 140 "
141 — 160 "
MORE THAN 161 "
NO DATA OF MEASUREMENT AVAILABLE

Fig. 12 Distribution of hooking-rate of yellowfin of various size classes in the Pacific Ocean: July to September

Scale of histogram: 10 degrees of longitude correspond to 5% of hooking-rate.

(See footnote 3/ of text for explanation.)

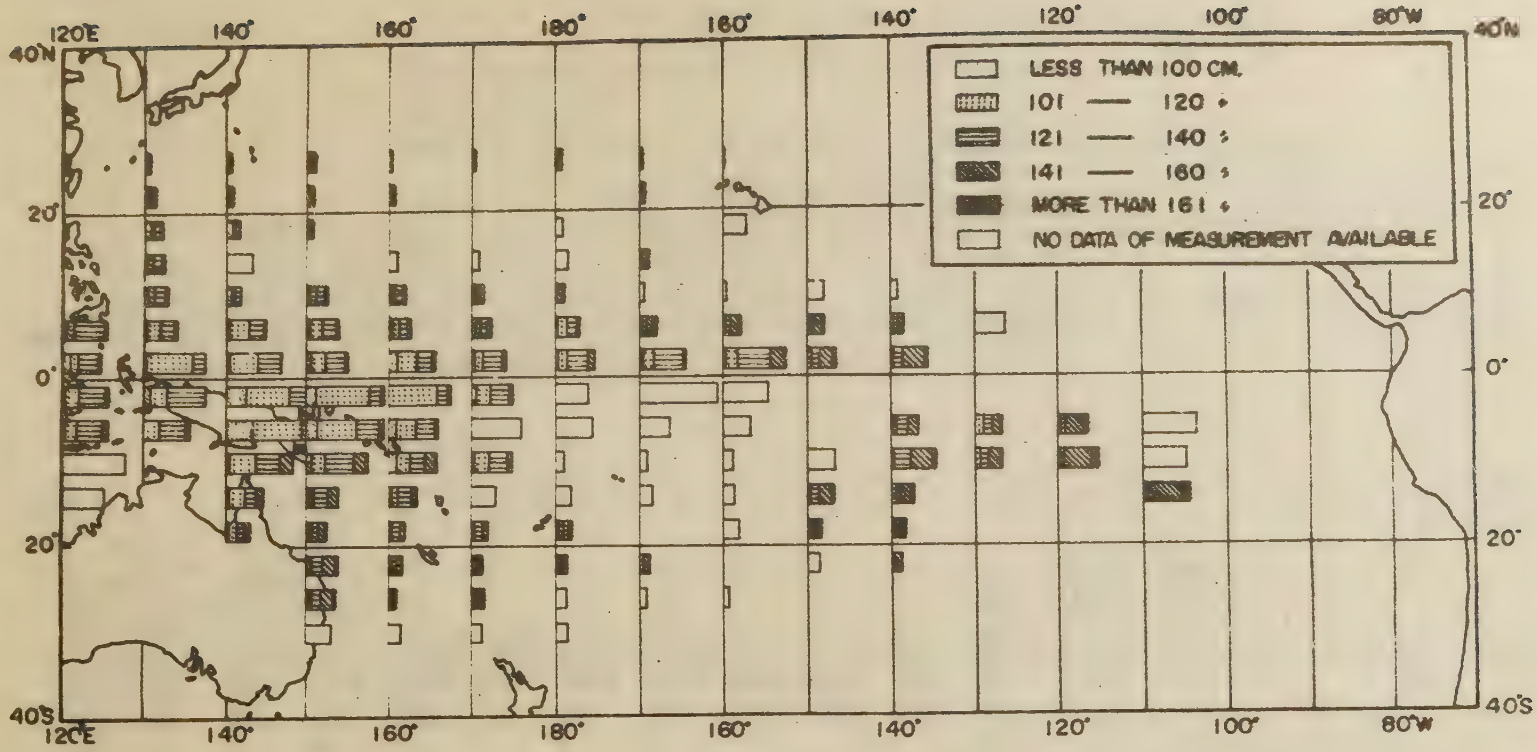
120°E
140°
160°
180°
160°
140°
120°
100°
80°W
40°N
20°
0°
20°
40°S
LESS THAN 100 CM.
101 — 120 〃
121 — 140 〃
141 — 160 〃
MORE THAN 161 〃
NO DATA OF MEASUREMENT AVAILABLE

Fig. 13 Distribution of hooking-rate of yellowfin of various size classes in the Pacific Ocean: October to December

Scale of histogram: 10 degrees of longitude correspond to 5% of hooking-rate.

(See footnote 3/ of text for explanation).

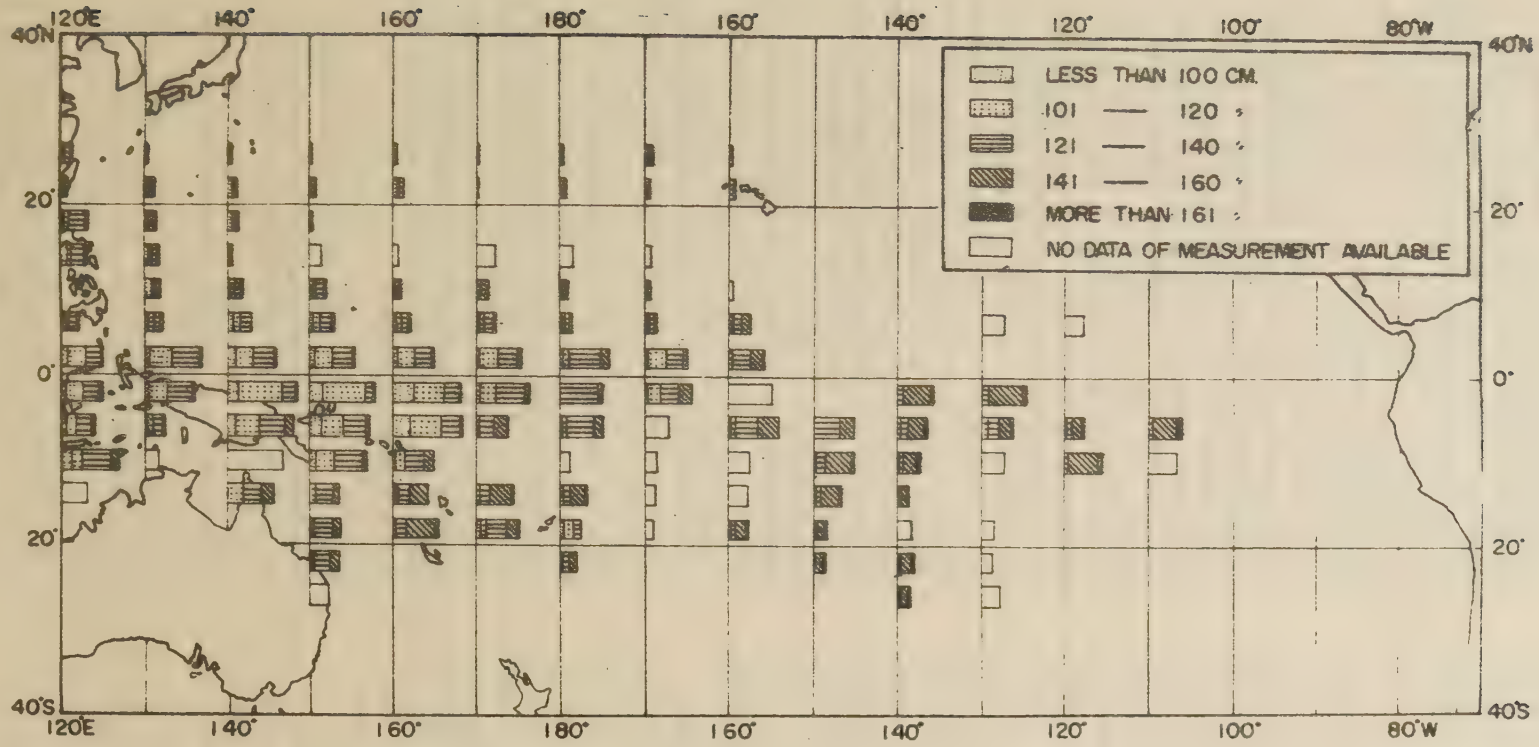
120°E
140°
160°
180°
160°
140°
120°
100°
80°W
40°N
20°
0°
20°
40°S
LESS THAN 100 CM.
101 — 120 "
121 — 140 "
141 — 160 "
MORE THAN 161 "
NO DATA OF MEASUREMENT AVAILABLE

Fig. 14 Distribution of hooking-rate of yellowfin of various size-classes in the Pacific Ocean: January to March

Scale of histogram: 10 degrees of longitude correspond to 5% of hooking-rate.

(See footnote 3/ of text for explanation.)

Some facts indicative of the presence of this north-south movement were found also in a survey of the geographical and seasonal occurrences of yellowfin contaminated with radioactive substances (Suda 1956). It seems clear from the above that, in middle latitudes of the Pacific the distribution (including abundance) of yellowfin exhibits comparatively simple seasonal variations which depend largely on north-south movements of fish concurrent with the seasonal change in the altitude of the sun.

Nakamura (1951) reported, from results of longline fishing by Japanese research and training vessels prior to the Second World War, that hooking-rates are highest about May and June in the eastern part of the Caroline Islands waters (0° - 10° N, 150° - 160° E). He also pointed out that two maxima of hooking-rate occur annually, namely in May and in December in Palau waters (7° - 8° N, 133° - 135° E). Murphy and Otsu (1954) showed that two maxima of hooking-rate occurred annually, namely in mid-summer and in mid-winter, in the Japanese mothership operations carried out in 1950 and 1951 between 1° to 5° N and 135° to 170° E. These maxima nearly coincide in time with those observed by Nakamura in Palau waters.

Nakagome (1958) reported that hooking-rates of yellowfin are highest in late spring and lowest in autumn between lat. 0° to 5° N and long. 140° E to 160° E. The season of highest hooking-rates as reported by Nakagome corresponds to one of the peaks reported by Nakamura and by Murphy and Otsu, but he did not refer to the presence or absence of another peak. On the other hand, Shomura and Murphy (1955) studied the seasonal variations in yellowfin abundance in the equatorial central Pacific chiefly on the basis of the results of POFI's investigations, and stated that the hooking-rate attains the maximum in different months in different longitudes: namely, in August-September in the vicinity of the Line Islands (0°-5° N, 150°-155° W), in May-June in the waters to the west, and in February-March in the waters to the east. They also pointed out that the maximum of hooking-rate occurred persistently in the same months for three successive years, 1951-1953, in the vicinity of the Line Islands. However, the reverse happened in 1954 in this region with the hooking-rates being highest in February and lowest from July through October (Iversen and Yoshida 1956). Yabuta et al (1958) and Yabuta and Yukinawa (1959) calculated monthly hooking-rates in different longitudes west to 160° W from the operation records of Japanese longline boats (Fig. 9). They found that the season in which the hooking-rate reached a maximum varied with longitude, and showed a tendency of being successively delayed from west to east. The maximum occurred between November and February in the western part of the investigated waters and between April and July in the eastern part.

It does not seem feasible to attempt to draw definite conclusions from these various results which disagree in so many respects. It seems noteworthy, however, that both Nakamura, and Murphy and Otsu recognized two maxima, i.e., two successive cycles of hooking-rate in the course of a year that were related to the aforementioned north-south movement of the fish. It does not seem that Nakagome's findings are fundamentally contradictory to those of Nakamura and of Murphy and Otsu in this respect. Furthermore, Yabuta et al (1958) and Yabuta and Yukinawa (1959) indicated that there is a tendency for two peaks to show up in the seasonal variation of hooking-rate when the data for different years are combined. While the peaks obtained in this manner correspond to those reported by Nakamura and by Murphy and Otsu in the time of occurence, they are not always separated clearly from each other, and there is no positive indication of the presence of two cycles of hooking-rate in the west of the 180° meridian.

Therefore, it is suspected that the occurrence of two maxima of cycles is a phenomenon peculiar to the western Pacific, provided that the results obtained by Nakamura and by Murphy and Otsu are true to fact, and also that hooking-rates are subject to a fundamentally different type of seasonal variation in the central Pacific.

Apart from the problem of periodicity indicated above, the successive lags in the occurrence of the hooking-rate maximum from west to east, as pointed out by Yabuta et al (1958) and Yabuta and Yukinawa (1959), also appears worthy of consideration. Since these authors based their conclusion on substantial quantities of data, it is very likely that this lag is real. It is possible that it is related to the tendency for yellowfin, with growth, to emigrate from the western Pacific toward the east (see section 4), since this type of lag could be produced by progressive eastward movement of the major concentration of the fish.

At any rate, it appears evident that seasonal variation of hooking-rate is indefinite and variable from one year to another. This is indicated by the discrepancy between the results of Shomura and Murphy (1955) and of Iverson and Yoshida (1956), and also by the considerable year-to-year variation in the trend of seasonal variation of hooking-rate as is observed in Fig. 9.

In contrast, in the equatorial region near the eastern extreme of the fishing ground (Fig. 10), where a belt or tongue of cold water protrudes westwards into the fishing ground along the Equator, distribution of the yellowfin exhibits distinct seasonal variations in correspondence to the varying strength of this tongue of cold water (Yabuta and Yukinawa 1959). Since the hooking-rate and the surface water temperature illustrated in Fig. 10 are based on data for different years, any detailed discussion of the parallel distribution of the two factors is not justifiable. However, it may be permissible to point out the following general correspondence: It can be observed in Fig. 10 that the strength of the cold water, as judged from the distribution of surface temperature, increases from April-June through October-December, and decreases from November-December through April-June. When the tongue of cold water is developed to its maximal strength (i.e., in October-December), the area of yellowfin abundance divides into two branches separated by the tongue of cold water on the Equator. In April-June, when the cold water tongue is at its lowest strength, dense distribution of the yellowfin is almost continuous across the Equator. This would seem to indicate that the cold water, when present, prevents the yellowfin from accumulating near the Equator.

Another interesting feature is the tendency for high concentrations of yellowfin to occur alternately to each side of the cold water. To the north of the Equator, and not on both sides simultaneously, the density of yellowfin is highest when the cold water is least developed (i.e., in April-June); to the south of the Equator it is highest when the cold water is most developed (i.e., in October-December). Thus, the seasonal change of hooking-rate on one side of the Equator is nearly opposite to that on the other side of the Equator. At present, sufficient data are not available for a meaningful discussion of the mechanism by which this phenomenon is brought about. It is felt that research with very broad perspectives is needed to determine whether this phenomenon reflects a south-north movement of the yellowfin.

5 DISTRIBUTION OF DIFFERENT SIZE-CLASSES

Figs. 11-14 show the distribution of yellowfin of various size-classes in the Pacific longline fishing ground for different seasons of the year. The data illustrated in these figures are based on the records of commercial boats and of size measurements taken on the commercial catch[1], and involve such uncertainties as will be discussed later. Inspection of these figures indicates the following general differences among the distribution of yellowfin of different size-classes throughout a year.

(a) "Small" yellowfin below 120cm. in body length (fork length) occur mainly to the west of the 180° meridian, and their densities are highest in the western part of the fishing ground, especially in the vicinity of the Solomon Islands and New Guinea.

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[1] The hooking-rates illustrated in Figs. 11-14 are based on the records of commercial longline boats and of size measurements taken on landed fish for the five years from April 1954 through March 1959. An operation record lists hooking-rates by species for each haul of longline, whereas size measurements were made on a sample of fish drawn from the catch made on each cruise. Hooking-rate data (by hauls) and size composition data (by cruises) are classified by "sea regions" (each bounded by 4 degrees of latitude and by 10 degrees of longitude) and by "seasons" of the year (i.e., April-June, July-September, October-December, and January-March). Those data belonging to each "sea region - season" category are averaged regardless of the year, to give an average hooking-rate and an average percentage size composition for each category. Multiplication of the two gives the average hooking-rate by size classes, which are entered in Figs. 11-14.

Size composition data are obtained on cruises. A cruise during which longline hauls are made in more than one "sea region" poses a problem. The data from such a cruise has been assigned to the "sea region" which contributed more than 60% of the catch of that cruise. If there was no such "sea region" the size composition data representing that cruise have usually been excluded from the calculations. Furthermore, a cruise in which the longline operation extended over two "seasons" has been assigned to that "season" in which a larger portion of the catch of the cruise was made.

(b) "Large" yellowfin above 141 cm. occur mainly to the east of the 180° meridian.

(c) Yellowfin of "medium" size, between 121 and 140 cm. occur more extensively than "small" or "large" fish, and are not confined to either the eastern or the western part of the fishing ground. Their distribution is of intermediate character between those of "small" and "large" fish.

It appears from the above that yellowfin of different size-classes occur over markedly different ranges of longitude, and that the center of distribution shifts from west to east with the growth of the fish.

The data illustrated in Figs. 11-14 involve the following uncertainties, however. First, the longline gear is not suited for catching small yellowfin, as was indicated earlier, because of its characteristic size selectivity. It is chiefly for this reason that the densities (i.e. hooking-rates) of "small" yellowfin are generally lower than those of "medium" or "large" fish in Figs. 11-14. Gear selectivity, though, is exerted in every part of the fishing ground indiscriminately, so that special importance need not be attached to it as far as we are to compare the relative densities of a given size-class in different regions. There are uncertainties ascribable to the following two factors, however, that are worthy of consideration, because the effects of these factors on the size composition of the catch are not the same in all parts of the fishing ground:

(1) Distance of fishing locality from land or islands

It has been shown that young yellowfin generally exhibit a strong tendency to inhabit the waters near land or islands in high densities (Murphy and Ikehara 1955; Shomura and Murphy 1955; Iversen and Yoshida 1957; Kawasaki 1958, 1960). While this tendency becomes less with the growth of the fish, it is still fairly distinct at those growth stages which correspond to the "small" group in the longline catch (Figs. 15-17). Consequently, in a sea region that is bordered by a continent or which includes islands, size composition of longline-caught yellowfin varies considerably with the distance of the fishing locality from land or islands. The data illustrated in Figs. 11-14 have not been corrected with regard to this local effect of land or islands and should perhaps be re-examined with this factor in mind. At present, the writers are not able to forecast the result of such re-examination quantitatively, but they would like to consider the problem qualitatively using the available data.

The records obtained by the Seiwa Maru in the waters near the Marquesas Islands (Fig. 16) are worthy of attention, because they suggest that the abundance of "small" yellowfin might be underestimated in the central and eastern Pacific as compared with the western Pacific in Figs. 11-14. On the other hand, there are reports which appear to suggest that the general picture of a real abundance of "small" yellowfin, as illustrated in Figs. 11-14, would remain relatively unchanged even if the data were corrected with regard to the effect of land or islands. According to Shomura and Murphy (1955) and Iversen and Yoshida (1957), dense distribution of small yellowfin occurred only within a relatively small area around the islands (within 80 sea miles, at most) in the Line Island waters. In addition, Iversen and Yoshida supposed that, in these waters, the quantity of the small yellowfin concentrating around the islands was not large enough to be regarded as the major source of recruitment for the stock of large yellowfin found in the contiguous open-sea areas. Murphy and Ikehara (1955) compiled the data on the sightings of surface schools of tunas in the central Pacific between longitude 180° to 110°W and latitude 30°N to 15°S. The schools sighted were composed of fish much smaller than those usually caught on the longline. Their results (Tables I-III) indicate that sightings are not frequent in general, and very infrequent in the open-sea regions.

When the data presented in the foregoing paragraph are considered altogether, it seems unlikely that the hooking-rates of "small" yellowfin in the central and eastern Pacific, as shown in Figs. 11-14, are underestimated to any considerable extent in relation to those in the western Pacific. It seems at least, permissable to presume that the general feature of distribution of "small" yellowfin as shown in Figs. 11-14 will not be altered significantly by correction of data with regard to the errors due to the local effect of land and islands.

(2) Fishing pressure and its effect on the size composition of the fish stock

A study is now in progress on the effect of exploitation on the size composition of the yellowfin population in the Pacific. This study

Table I

Summary of island observations of fish schools
(After Murphy and Ikehara (1955))

Locality	Period	Number of days		Yellowfin		Skipjack		Mixed 1/		Unidentified		Total fish schools	
		Fishing and scouting	Running	No.	No. per day	No.	No. per day	No.	No. per day	No.	No. per day	No.	No. per day
Line Is.	Mar.-May	26	6	16	0.5	0	0.0	2	0.1	15	0.5	33	1.0
	June-Aug.	4	3	13	1.9	1	0.1	4	0.6	3	0.4	21	3.0
	Sept.-Nov.	22	11	20	0.6	12	0.4	4	0.1	55	1.7	91	2.8
	Dec.-Feb.	8	19	7	0.3	4	0.1	3	0.1	24	0.9	38	1.4
Total and average 2/		60	39	56	0.8	17	0.2	13	0.2	97	0.9	183	2.1
Phoenix Is.	Mar.-May	-	3	0	0.0	0	0.0	0	0.0	2	0.7	2	0.7
	June-Aug.	3	4	8	1.1	6	0.9	0	0.0	5	0.7	19	2.7
	Sept.-Nov.	0	2	3	1.5	2	1.0	0	0.0	2	1.0	7	3.5
	Dec.-Feb.	3	14	3	0.2	1	0.1	0	0.0	5	0.3	9	0.5
Total and average 2/		6	23	14	0.7	9	0.5	0	0.0	14	0.7	37	1.9
Hawaiian Is.	Mar.-May	0	9	0	0.0	7	0.8	0	0.0	7	0.8	14	1.6
	June-Aug.	33	15	4	0.1	81	1.7	0	0.0	20	0.4	105	2.2
	Sept.-Nov.	4	31	0	0.0	17	0.5	0	0.0	21	0.6	38	1.1
	Dec.-Feb.	0	4	1	0.2	1	0.2	0	0.0	1	0.2	3	0.8
Total and average 2/		37	59	5	0.1	106	0.8	0	0.0	49	0.5	160	1.4
Leeward Is.	Mar.-May	1	4	1	0.2	3	0.6	0	0.0	25	5.0	29	5.8
Jarvis I.	June-Aug.	1	0	2	2.0	0	0.0	0	0.0	1	1.0	3	3.0
	Dec.-Feb.	1	1	0	0.0	0	0.0	0	0.0	3	1.5	3	1.5
Malden I.	Sept.-Nov.	1	0	0	0.0	2	2.0	0	0.0	4	4.0	6	6.0
Starbuck I.	Dec.-Feb.	1	0	0	0.0	3	3.0	0	0.0	0	0.0	3	3.0
Johnston I.	Mar.-May	0	2	0	0.0	0	0.0	0	0.0	5	2.5	5	2.5
Marquesas Is.	June-Aug.	0	2	0	0.0	2	1.0	0	0.0	0	0.0	2	1.0
Samoa Is.	Dec.-Feb.	0	1	0	0.0	2	2.0	0	0.0	7	7.0	9	9.0
Nukunono Is.	Dec.-Feb.	0	1	0	0.0	0	0.0	0	0.0	1	1.0	1	1.0

1/ Yellowfin and skipjack

2/ Unweighted averages

Table II

Summary of semioceanic[1] observations associated with particular island groups (After Murphy and Ikehara (1955))

Locality	Period	Number of days		Yellowfin		Skipjack		Unidentified		Total fish schools	
		Fishing and scouting	Running	No.	No. per day	No.	No. per day	No.	No. per day	No.	No. per day
Line Is.	Mar.-May	0	1	0	0.0	1	1.0	0	0.0	1	1.0
	June-Aug.	0	2	0	0.0	0	0.0	0	0.0	0	0.0
	Sept.-Nov.	0	3	1	0.3	2	0.7	6[2]	2.0	9	3.0
	Dec.-Feb.	0	17	0	0.0	10	0.6	21	1.2	31	1.8
Total and average[3]		0	23	1	0.1	13	0.6	27	0.8	41	1.4
Phoenix Is.	Mar.-May	0	4	0	0.0	1	0.2	4	1.0	5	1.2
	June-Aug.	0	2	2	1.0	3	1.5	1	0.5	6	3.0
	Sept.-Nov.	-	-	-	-	-	-	-	-	-	-
	Dec.-Feb.	0	4	0	0.0	0	0.0	0	0.0	0	0.0
Total and average[3]		0	10	2	0.3	4	0.6	5	0.5	11	1.4
Hawaiian Is.	Mar.-May	0	10	0	0.0	3	0.3	5	0.5	8	0.8
	June-Aug.	1	8	0	0.0	4	0.4	10	1.1	14	1.6
	Sept.-Nov.	0	16	0	0.0	10	0.6	7	0.4	17	1.1
	Dec.-Feb.	0	7	0	0.0	1	0.1	1	0.1	2	0.3
Total and average[3]		1	41	0	0.0	18	0.4	23	0.5	41	1.0
Leeward Is.	Mar.-May	0	2	0	0.0	2	1.0	1	0.5	3	1.5
Jarvis I.	Sept.-Nov.	0	1	0	0.0	0	0.0	0	0.0	0	0.0
	Dec.-Feb.	0	2	0	0.0	2	1.0	0	0.0	2	1.0
Malden I.	June-Aug.	0	1	0	0.0	1	1.0	0	0.0	1	1.0
Starbuck I.	Sept.-Nov.	0	1	0	0.0	0	0.0	2	2.0	2	2.0
	Dec.-Feb	0	5	0	0.0	2	0.4	17	3.4	19	3.8
Johnston I.	Mar.-May	0	1	0	0.0	1	1.0	0	0.0	1	1.0
Marquesas Is.	Mar.-May	0	1	0	0.0	0	0.0	0	0.0	0	0.0
	June-Aug.	0	4	0	0.0	1	0.2	3	0.8	4	1.0
Samoa - Nukunono Is.	Dec.-Feb.	0	3	0	0.0	0	0.0	2	0.7	2	0.7

[1] Semioceanic observations were considered to be from 60 to 180 miles from the islands

[2] Two schools of little tuna

[3] Unweighted averages

Table III

Summary of oceanic observations of fish schools.
The sightings are summarized by rectangles bounded by 10° of latitude and 10° of longitude and identified by coordinates of the southeast corner (After Murphy and Ikehara, 1955)

Location	Number of days	Fish schools			
		Yellowfin	Skipjack	Unidentified	Total
20°N - 110°W	2	-	-	-	-
20°N - 150°W	5	-	-	-	-
20°N - 160°W	1	-	-	-	-
20°N - 170°W	1	-	-	-	-
10°N - 110°W	2	-	-	2	2
10°N - 120°W	1	-	-	3	3
10°N - 130°W	5	1	-	2	3
10°N - 140°W	16	-	1	8	9
10°N - 150°W	32	-	7	12	19
10°N - 160°W	29	-	1	-	1
0° - 120°W	2	-	-	-	-
0° - 130°W	12	1	1	2	4
0° - 140°W	18	1	5	5	11
0° - 150°W	9	1	3	8	12
0° - 160°W	22	-	-	8	8
0° - 170°W	11	-	-	1	1
0° - 180°	1	-	-	-	-
10°S - 120°W	4	-	3	6	9
10°S - 130°W	4	-	-	-	-
10°S - 140°W	9	-	-	1	1
10°S - 150°W	2	-	1	-	1
10°S - 160°W	9	1	8	8	17
10°S - 170°W	8	-	-	4	4
Total	205	5	30	70	105

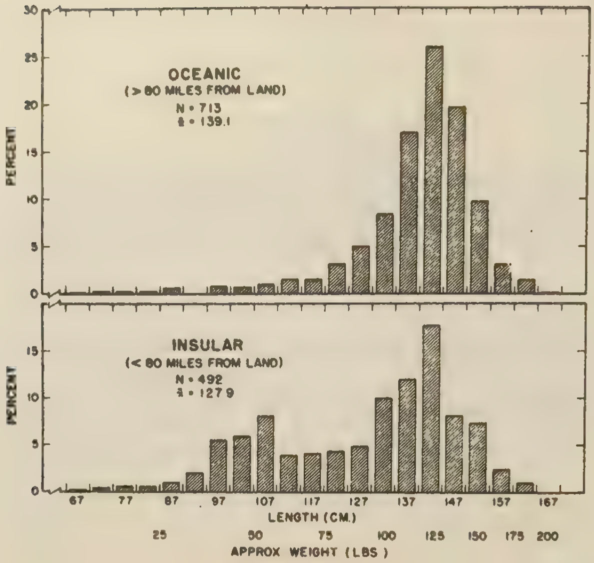

Fig. 15 Size distribution of yellowfin with distance from land (after Shomura and Murphy (1955))

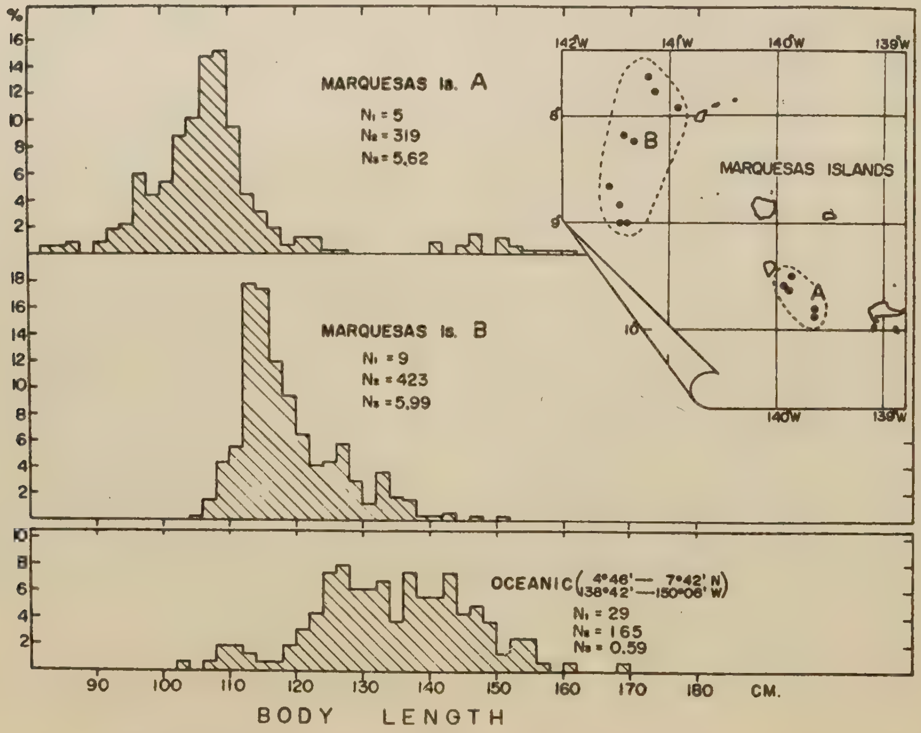

Fig. 16 Size distribution of yellowfin caught in the neighborhood of the Marquesas Islands and in an open-sea area.

(Based on the data taken by the Seiwa Maru in the cruise from August through October 1960)

N_1: number of longline operations

N_2: number of yellowfin measured

N_3: mean hooking-rate (%)

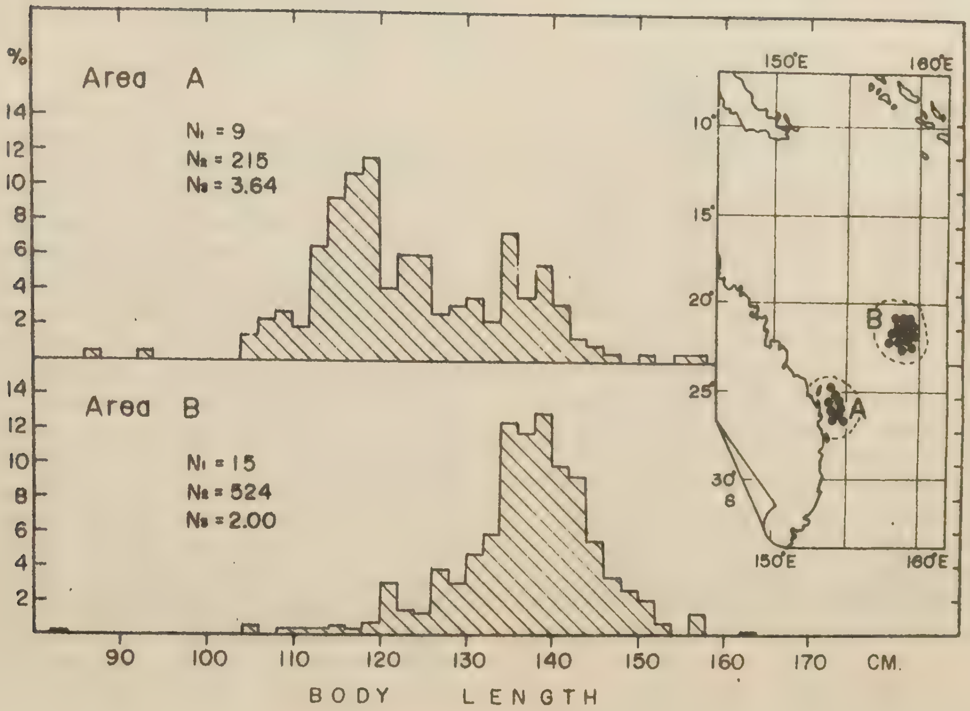

Fig. 17 Size distribution of yellowfin to the east of Australia with distance from land

(Based on the data taken by the Fukushima Maru in the cruise in August 1958)

N_1: number of longline operations

N_2: number of yellowfin measured

N_3: mean hooking-rate (%)

has been undertaken as a part of a program which is aimed at an analysis of causes of fluctuation in the stock of the Pacific yellowfin. Although no definite conclusions have yet been arrived at in this study, it appears that the yellowfin currently caught in the western Pacific are somewhat smaller in average size than those taken when the fishery was originated in these waters. It has not yet been determined, however, whether this decrease in average size of landed fish reflects any change in the size composition of the yellowfin stock due to fishing pressure. Fishing pressure (or any change produced thereby in the size composition of the yellowfin population) cannot be regarded as the major factor responsible for the tendency for different size classes to have different hooking-rates in different ranges of longitude, for the following reasons: first, the abundance of "small" yellowfin (as indicated by hooking-rate) differs markedly in different regions, despite the fact that these fish have not previously been exposed to fishing; second, in the eastern waters "small" yellowfin are very sparse, in spite of the fact that "large" fish are predominant.

The discussions in the foregoing paragraphs point to the following conclusion: There is a tendency for the yellowfin of different size-classes to occur in different ranges of longitude in the western and central Pacific; but there is the possibility that this tendency is exaggerated in Figs. 11-14 by either or both factors (1) and (2). Determination of the errors due to these factors, as well as a quantitative description of the above mentioned tendency, which is linked with the movement and the mixing of fish within the yellowfin population, is an important subject for future study.

6 SOME CONSIDERATION ON THE PROBLEM OF SUBPOPULATIONS

The problem of subpopulations of the Pacific yellowfin has so far been approached mainly through morphological studies by Godsil (1948), Godsil and Greenhood (1951), Schaefer (1952, 1955), Royce (1953), Tsuruta (1954, 1955), Kurogane and Hiyama (1957), Kurogane (1960) and others. These previous authors all recognized differences in external morphology between the samples of yellowfin from different parts of the Pacific Ocean, and presumed, on the basis of these differences, the presence of two or more independent or semi-independent subpopulations or stocks of yellowfin. However, they do not concur with one another in the identities and diagnostic morphological characteristics of the subpopulations they proposed, and the disagreement among the authors has not been successfully reconciled.

With the progress of the studies, there has been a notable change in the concept of the population structure of the Pacific yellowfin. In the beginning, there was a tendency to interpret the presence of morphological differences as an indication of rather complete geographic isolation, and to presume the presence of highly independent groups or subpopulations, whereas in later studies, the whole population of the yellowfin is regarded as being composed of semi-independent groups among which partial intermingling takes place. This change may be regarded as progress, when viewed in the light of the knowledge of the distribution pattern of the yellowfin. Since the distribution of the yellowfin is continuous in both north-south and east-west directions over the Pacific longline fishing grounds, as mentioned in section 1, it is properly expected that neighboring regional groups would have mutual influences through intermingling.

It may be safely presumed that the yellowfin population consists neither of a single, well-mixed, homogeneous population nor of two or more highly independent geographic groups, but is represented by a state intermediate between the two. Then, it is reasonably supposed that future studies of the subpopulations of the Pacific yellowfin will be focused on the following question: By what mechanism and to what extent are the different geographic groups isolated or intermingled?

From this point of view, the recent paper by Royce (1961) appears worthy of attention. This paper was presented at the Pacific Tuna Biology Conference held at Honolulu in Agust 1961. In this work, the author estimated, on the basis of morphometric data, the percentage overlap of different regional groups of yellowfin in the equatorial waters of the Pacific. He stated that the percentage overlap decreases rapidly with the increase in the distance between samples, but independently of the size of fish (Fig. 18). From this result, he presumed that the majority of the yellowfin remains within several hundred miles of the spot where they made their appearance as juveniles. It is worthy of attention that this presumption fundamentally conflicts with the tendency, indicated in the foregoing chapter,

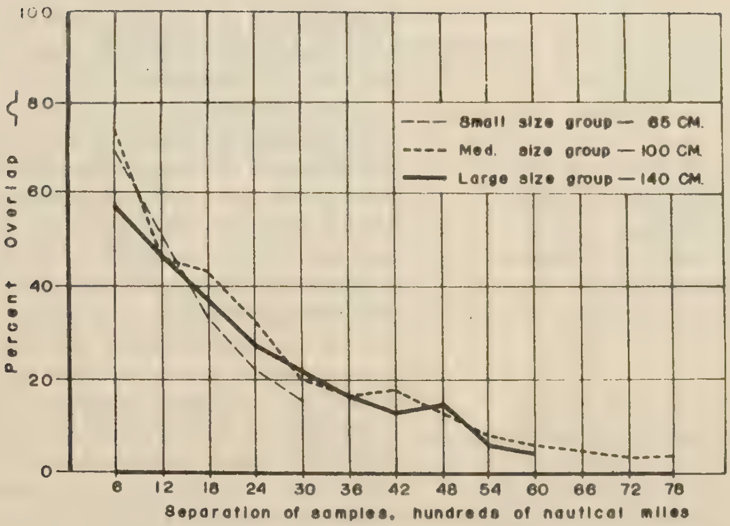

Fig. 18 Average overlap of samples of yellowfin from the Pacific equatorial zone (after Royce 1961)

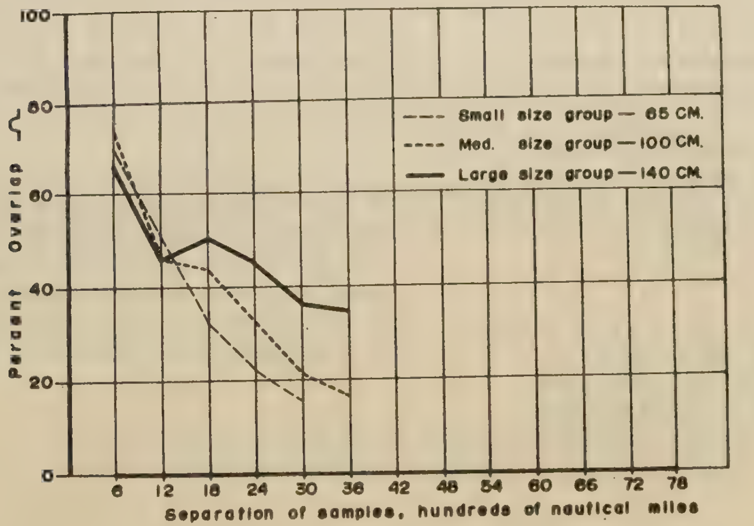

Fig. 19 Average overlap of samples of yellowfin from the Pacific equatorial zone west to long. 150°W (computed from Table XIV of Royce 1961)

hat different size-classes have different eographic distributions.

The aforesaid tendency suggests the following possibilities:

(1) "Small" yellowfin are abundant in the western Pacific, especially the waters near the Solomon Islands and New Guinea. They exhibit a strong tendency to migrate eastward into the open sea region, and they may eventually move into the central Pacific as "large" yellowfin.

(2) In the western Pacific, growth is the major factor controlling any extensive eastward or westward movement of yellowfin. Although the yellowfin of various size-classes may move in the east-west direction seasonally, this movement is very limited in extent as compared with the extensive movement that is associated with the life cycle of the fish.

Combination of (1) and (2) suggests that both the distance covered by, and the extent of intermingling due to, the east-west movement of the fish increase with growth of the fish. This is evidently inconsistent with Royce's result.

However, it should be pointed out that Royce's work involved the following problem:

(a) His samples for the western Pacific were restricted to the north of the Equator, and do not represent the waters south of the Equator, where the yellowfin occurs in highest densities.

(b) Percent overlap was computed without regard to the fact that his samples of different size groups (65 cm., 100. and 140 cm. respectively) covered different geographic ranges.

The present writers have no further comment in connection with (a). As for (b), however, they should like to point out that the method employed by Royce in processing the data is justifiable on the condition that the relationship between percent overlap and the distance between samples does not vary throughout the range of sampling area. Royce does not explain whether his condition was satisfied or not. The present writers tentatively calculated percent overlap, by the same method as was employed by Royce, for his sample taken in the west of the Line Islands (i.e., west of about long. 150° W). In this area similar numbers of samples are available for the three size groups. The percent overlap obtained in this manner (Fig. 19), considering its absolute value alone, shows a distinct tendency to increase with the size of fish. This result is rather in line with the foregoing hypotheses (1) and (2).

It is, therefore, suggested that, although the result obtained by Royce concerning the percent overlap and those of the present writers concerning the distribution of various size-classes suggest different patterns of emigration and intermingling, this discrepancy is not fundamental, but has most probably been caused by the way in which Royce processed his data. At present, the writers are not able to discuss this matter in further detail.

Apart from this problem, it is emphasized that oceanographic and environmental conditions are different in the western and central Pacific, as mentioned earlier in this paper, and that this fact should not be neglected in considering the mixing within the yellowfin population in the Pacific Ocean.

Experience Paper No. 18

A REVIEW OF THE FRIGATE MACKERELS (GENUS AUXIS) OF THE WORLD

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Abstract

Based upon an examination of 147 adult Auxis from many localities, primarily north of the equator, it was concluded there are two valid species. Auxis thazard, a narrow-corseleted species with thin, oblique, wavy markings on the back is confined to the Pacific, but Auxis rochei, which has a wide corselet of scales and a pattern of broad, nearly vertical dark bars, is cosmopolitan in distribution.

No one has yet found a means of identifying larval, post-larval or juvenile Auxis to species because the distinguishing corselet and dorsal markings are not developed until these fish are about 200 mm long.

ENQUETE SUR LES AUXIDES (GENRE AUXIS) DES DIFFERENTES PARTIES DU MONDE

Résumé

A la suite de l'examen de 147 Auxis adultes pêchés en de nombreux lieux, principalement dans l'hémisphère nord, on est parvenu à la conclusion qu'il existe réellement deux espèces. Auxis thazard, poisson présentant un corselet d'écailles étroit et de fines marques dorsales obliques et ondulées, ne se trouve que dans le Pacifique, tandis que

Auxis rochei, qui possède un large corselet et, dans la région dorsale, de larges marbrures foncées presque verticales, se trouve dans toutes les mers.

On n'a pas encore trouvé un moyen de déterminer l'espèce des Auxis aux stades larvaires, postlarvaires ou immatures, du fait que le corselet et les marques dorsales distinctifs n'apparaissent que lorsque le poisson atteint environ 20 cm. de long.

ANALISIS MUNDIAL SOBRE LA MELVA (GENERO AUXIS)

Extracto

Partiendo del examen de 147 ejemplares adultos de Auxis, procedentes de muchos lugares y, principalmente, del norte del Ecuador, se llegó a la conclusión de que existen dos especies válidas. Auxis thazard, que se caracteriza por su corselete angosto y por las estrías onduladas que atraviesan oblicuamente el lomo, es propia exclusivamente del Pacífico; pero Auxis rochei, con corselete ancho y una serie de franjas anchas y oscuras, casi verticales, es cosmopolita.

Nadie ha descubierto todavía un medio de identificación de Auxis como especie en su estado larval, poslarval o juvenil, porque el corselete y las estrías dorsales que caracterizan a este género, no se desarrollan hasta que el pez mide 200 mm. de longitud.

1 INTRODUCTION

Whether the frigate mackerels, genus Auxis, properly should be referred to a single cosmopolitan species or to several species with more limited distributions has remained an open question for many years. Most of this confusion has stemmed from the general similarity of these fish in different areas of the world and from a lack of sufficient material upon which to base an opinion. Under the circumstances, it has been common practice to regard Auxis thazard (Lacèpède 1802) as cosmopolitan and to place in synonymy with it the several species since described.

In recent years, we have examined numerous adult Auxis from the eastern tropical Pacific Ocean representing two unquestionably distinct species. When we attempted to determine how the two fitted into the world-wide picture, it became obvious that we would have to make detailed examinations of as many specimens from as many geographic localities as we could obtain. The present paper is based upon the results of this work.

2 HISTORICAL RESUME

The frigate mackerels were first recognized in 1802 when Lacèpède described Scomber thazard from a specimen collected by Commerson off the New Guinea coast near lat. 07°S in 1768. Eight years later, in 1810, two scientists, Risso and Rafinesque, unbeknownst to each other named the Mediterranean frigate mackerel Scomber rochei and Scomber bisus respectively. Systematists have generally followed Günther (1860) and Jordan and Gilbert (1883) in accepting Risso's rochei as having priority over Rafinesque's bisus, and Cuvier in 1829 designated rochei as the type species for his genus Auxis; however, the International Commission of Zoological Nomenclature has never ruled as to which name, rochei or bisus, is valid.

Seven additional specific names have been applied to frigate mackerels from world seas during intervening years. These include rocheanus Risso, 1826 (Mediterranean), vulgaris Cuvier, 1831 (Mediterranean), taso Cuvier, 1831 (New Guinea), tapeinosoma Bleeker, 1854 (Japan), thynnoides Bleeker, 1855 (Ternate), hira Kishinouye, 1915 (Japan), and maru Kishinouye, 1915 (Japan).

All other workers discussing the frigate mackerels have been satisfied to use whichever of these ten names they felt were applicable in their areas.

3 DISTINGUISHING CHARACTERISTICS

3.1 For the genus

Members of the genus Auxis can be distinguished at all sizes from all other scombrids except Scomber and Pneumatophorus by their widely-separated dorsal fins. They can be told from these two genera by their eight dorsal and seven anal finlets; Scomber and Pneumatophorus, have five of each.

3.2 For the species

When an array of Auxis from all of the world seas is displayed on a table for comparison three immediately observable characters will separate the array into two groups. One group will contain fish having a pattern of 15 or more narrow, oblique to nearly horizontal, dark wavy lines in the bare (scaleless) area on each side of the back, the tip of the pectoral extending beyond a vertical from the anterior end of the elongate scaleless area on the back, and from one to three scale rows in the corselet along the lateral line where it passes beneath the insertion of the second dorsal fin. The fish in the other group will have 15 or more fairly broad, nearly vertical bars in the bare area (some bars may branch dorsally or break up into spots and blotches), pectoral fins that fail to reach to a vertical beneath the anterior end of the bare area, and more than six rows of scales in the corselet where it passes beneath the insertion of the second dorsal fin.

When the array has been separated into these two groups, a glance at locality labels will show that all of the wavy-lined, narrow, corseleted ones are from the Pacific (western, central and eastern) while those with vertical bars and wide corselets are cosmopolitan(Pacific, Atlantic and Mediterranean).

3.2.1 The narrow-corseleted form

From the type description, (the type is no longer in existence) the wavy-lined, narrow-corseleted form has to be Auxis thazard (Lacépède 1802). We examined 84 of these from throughout the Pacific region to which they are confined and although we found slight differences between the populations in widely-separated geographic localities, they were not of sufficient magnitude to warrant even subspecific separation. Synonyms of *thazard* are *taso*, *tapeinosoma* and *hira*.

3.2.2 The wide-corseleted form

As with the narrow-corseleted *Auxis*, we found slight variations in the wide-corseleted frigate mackerels from widely-separated geographic localities. These differences, as will be shown later, were progressive in a west to east direction and were so subtle for adjoining populations that we feel it is neither wise nor correct to consider them other than population differences. This form then must be assigned the specific name *rochei* (Risso 1810), assuming it in fact holds priority over *bisus*. Other synonyms of *rochei* include *rocheanus*, *vulgaris*, *thynnoides* and *maru*.

4 DISCUSSION

4.1 General

In our work on *Auxis*, we have dealt only with speciation, making no attempt to elucidate the problems of higher classification. To avoid encumbering our synopsis with a lengthy list of references, we have included only real (first-order) synonyms.

In our initial efforts, we attempted to delineate specific differences through analysis of routine counts and measurements of external features. Some of the answers we sought could not be derived from these generally-accepted methods so we made more-detailed studies when necessary. In order to determine skeletal structures, scale formation, etc., a series of juveniles, 13.2 to 89.0 mm standard length, was cleared and stained, and several adult *Auxis* of both species were dissected and skeletonized.

4.2 Meristic counts and proportional measurements

4.2.1 For *Auxis thazard*

We routinely took about 25 measurements and made counts on some 10 structures on each *Auxis* examined. Our material of *A. thazard* consisted of 60 adults, 273 to 405 mm fork length, from the eastern Pacific (Huntington Beach, California to Peru and the Galapagos Islands); 14 adults, 259 to 397 mm fork length, from the central Pacific (Hawaii); and 10 adults, 206 to 418 mm fork length, from the western Pacific (Japan, China, Korea, Java and the Philippines) for a total of 84.

Analyses of the measurements failed to reveal significant differences among the narrow-corseleted Auxis from these three widely-separated areas (Table I); however, from gill-raker counts (Table II), it would seem the eastern Pacific population is separable from those in the central and western Pacific.

In an effort to find additional differences, gill filaments on the ceratobranchial and lateral line scales were counted, but even these time-consuming, difficult-to-make counts did not separate these populations. The fact we could find no other differences plus a knowledge that *A. thazard* is abundantly distributed throughout the ocean area between Hawaii and western America, leads us to believe the differences in gill raker counts would become a gradual and progressive gradient (cline) upon examination of extensive material from intermediate oceanic localities.

4.2.2 For *Auxis rochei*

Our material of *A. rochei* consisted of 28 adults, 262 to 366 mm fork length, from the eastern Pacific (Huntington Beach, California to Callao, Peru); 2 adults, 281 and 286 mm fork length, from the central Pacific (Hawaii); 6 adults, 212 to 259 mm fork length, from the western Pacific (Japan, Philippines and Bleeker's type of *thynnoides* from Ternate); 3 adults, 381 to 416 mm fork length, from the eastern Atlantic (Mediterranean); and 24 adults, 288 to 359 mm fork length, from the western Atlantic (Massachusetts to North Carolina), a total of 63.

Measurements as percentages of standard length (Table III) show apparent differences among areas, especially in depth and width, but these are associated with length of fish. Gill raker and other counts (fin rays, lateral line scales, gill filaments) showed no differences from one area to another. There did appear to be differences in the average number of scale rows in the corselet, counted where it passes vertically beneath the second dorsal insertion. Matsumoto (1960) pointed out that the number of scale rows in the corselet increased with fish length (age) but because he had material only from Hawaii and the western Pacific he missed seeing that there also is an increase in the average number of scale rows for similar-sized fish from west to east. *Auxis rochei* in the western Atlantic have the fewest scale rows in their corselets while those in the eastern Pacific have the most. In fact, if a person considered only this feature and compared wide-corseleted *Auxis* from these two areas he would have no alterna-

Table I

Selected measurements for 84 specimens of
Auxis thazard from three geographic localities

Geographic Locality	Number of Specimens	Ranges in s.l. (mm)	Ranges in Percent of Standard Length			
			Head	Eye	Snout	Pectoral length
Western Pacific	10	200-402	26.5-28.9	4.7-5.5	6.3-7.5	12.2-14.2
Central Pacific	14	248-384	27.5-29.4	4.8-5.5	6.4-7.4	13.1-14.9
Eastern Pacific	60	263-392	27.4-29.5	4.2-5.1	5.7-6.8	12.7-14.6

Geographic Locality	Number of Specimens	Ranges in s.l. (mm)	Ranges in Percent of Standard Length				
			Snout to First Dorsal	Snout to Second Dorsal	Snout to Anal	Depth	Width
Western Pacific	10	200-402	30.6-33.2	61.5-66.2	67.8-72.2	21.5-25.2	14.6-17.2
Central Pacific	14	248-384	32.3-33.6	62.6-66.9	68.3-72.1	20.6-25.3	15.1-19.5
Eastern Pacific	60	263-392	31.8-34.5	64.6-69.0	68.3-74.2	22.4-26.4	16.7-20.2

Table II

Comparison of gill raker counts for 84 *Auxis thazard* from three geographic localities

	Number of Rakers On First Arch														
Area	Upper limb					Center 1/	Lower Limb								
	8	9	10	11	12	1	28	29	30	31	32	33	34	35	36
Western Pacific	1	7	1	1		10	1	1	5	2	1				
Central Pacific		6	8			14		3	6	5					
Eastern Pacific		4	31	24	1	60			1	5	11	14	19	9	1

1/ On all specimens the center raker has roots extending into both limbs.

Area	Total Number of Rakers									
	38	39	40	41	42	43	44	45	46	47
Western Pacific	2		4	2	1	1				
Central Pacific		3	2	5	4					
Eastern Pacific				1	5	8	13	15	11	7

Table III

Selected measurements for 63 specimens of *Auxis rochei* from five geographic localities

Geographic Locality	Number of Specimens	Ranges in s.l. (mm)	Ranges in Percent of Standard Length			
			Head	Eye	Snout	Pectoral length
Western Atlantic	24	277-347	26.2-28.0	4.5-5.1	6.0-7.3	12.0-14.0
Eastern Atlantic	3	368-398	26.1-26.9	4.6	6.3-6.6	12.2-12.7
Western Pacific	6	206-250	26.0-27.8	4.8-5.4	5.8-6.8	11.7-13.2
Central Pacific	2	272-277	27.4-27.8	5.1	6.6-7.2	13.1-13.7
Eastern Pacific	28	253-352	26.4-28.1	4.5-5.3	5.3-6.6	12.2-13.9

Geographic Locality	Number of Specimens	Ranges in s.l. (mm)	Ranges in Percent of Standard Length				
			Snout to First Dorsal	Snout to Second Dorsal	Snout to Anal	Depth	Width
Western Atlantic	24	277-347	30.7-33.3	63.3-67.8	68.2-73.9	20.5-24.2	14.7-18.1
Eastern Atlantic	3	368-398	30.7-31.9	66.4-68.6	71.1-72.4	23.2-23.6	17.9-20.6
Western Pacific	6	206-250	30.4-32.5	64.0-65.8	68.8-72.8	19.8-21.4	13.3-16.1
Central Pacific	2	272-277	31.3-32.5	65.1-66.8	71.3-71.5	20.6-21.0	14.7-15.2
Eastern Pacific	28	253-352	30.7-33.0	65.4-68.3	68.0-74.0	22.1-24.3	16.4-18.9

tive but to consider them specifically distinct. This points up the danger of deciding speciation for a widely-distributed form by examining material from only the extremes of its distribution.

We found it very difficult, if not impossible, to make an exact count of scale rows in the corselet on most specimens, and often had to resort to counting scale pockets to arrive at an approximation. The marginal corselet scales are highly deciduous, and many had been lost when the fish was handled on a fishing boat or enroute to the laboratory. Also, scales may be rubbed off by packing specimens too tightly when preserving them for storage. This loss of scales plus a tendency for the dorsal pattern to fade and disappear can result in misidentification unless extreme care is used when making specific determinations on preserved specimens that have not received the best of treatment. Our counts (Table IV) emphasize these difficulties when it is realized that our two central Pacific specimens yielded counts of 16 to 18 for Matsumoto (1960) yet the most we could distinguish were 15.

4.3 Larval characters

In the tropical eastern Pacific the larval scombrids most frequently captured under a night light are frigate mackerel. Although no special attempt was made to capture Auxis in preference to other species, as many as 419 were dipnetted at a single collecting station in a few hours and over 1,680 were taken during a single cruise from February to June 1954 (Clemens, 1957). Within the area bounded by Baja California, Peru and the Galapagos Islands, larval, post-larval and juvenile Auxis have been captured in numbers during every month of the year. Their growth during the juvenile stage is phenomenal. Clemens (1956) reported that two specimens 20 and 30 mm long placed in an aquarium aboard ship grew an estimated 40 and 46 mm respectively in six days.

We were unable to differentiate juveniles, through 105 mm standard length, of the two species inhabiting the eastern Pacific, nor could these be distinguished from similar-sized Auxis from the Mediterranean. Although Wade (1949) was able to separate comparable-sized juveniles of the two in Philippine waters by their gill raker counts, this method could not be applied to Auxis from the eastern Pacific because of the similarity in counts in these waters.

When 10 eastern Pacific juveniles, 13.2 to 89.0 mm standard length, were cleared and stained with alizarin we found that all dorsal and anal fin rays and finlets were sufficiently ossified to take a stain and all except those in the dorsal interspace were at their full adult complement (Table V). The dorsal interspace at these sizes contains a number of free rays which, in adult fish, are completely covered by integument and can be located only by careful dissection. In the 13.2 mm fish only three of these rays were developed and these were in the anterior portion of the interspace. The five observed on the 20 mm specimen did not fill its interspace, but the six, seven, and eight rays noted in the remaining specimens did and probably represented full complements.

The number of gill rakers on the first arch increases with fish length and Auxis 55 mm standard length and longer probably have their full quota.

The vertebrae were completely ossified in all 10 specimens but the first haemal arch was on different vertebrae in the juveniles than it is in adults. In adult Auxis, the first haemal arch is on the 21st vertebra, as is the first haemal spine. Progressing from the smallest to the largest of nine of our ten stained juveniles, we located the first haemal arch on vertebrae that were successively more posterior, but we did not find any where it was on the 21st (Table V). This means that, between a length of less than 20 mm and adulthood, Auxis must resorb at least eight haemal arches. Schaefer and Marr (1948) reported that the first haemal arch occurred on vertebra 18 on a specimen 72 mm standard length and probably was closed on vertebra 17 in specimens 25 and 46 mm long. Based upon these observations they concluded, "It seems unlikely that haemal arches that are closed would, with growth, become open. Our specimens may, therefore, be juveniles of an undescribed species." Resorption of haemal arches has, however, been demonstrated for a goby, Clevelandia ios (Clothier, 1946).

The lateral line of a 39 mm Auxis contained 25 scales and ended at a point vertically beneath the 8th dorsal spine. The three scale rows above the lateral line (at the shoulder) contained two, three, and two scales respectively while the four rows below the lateral line contained five, four, two and two respectively. There was a row of scales on each side of the base of the first dorsal fin and a row along the margin of the pectoral girdle below the pectoral base.

Table IV

Number of scale rows under second dorsal insertion in *Auxis rochei*

Geographic Locality	Number of Specimens	Ranges in Fork Lengths	Ranges in Scale Rows
Western Atlantic	24	288-359	6-9
Eastern Atlantic	3	381-416	7-10
Western Pacific	6	219-259	9-13 1/
Central Pacific	2	281-286	11-15 1/
Eastern Pacific	28	262-366	13-28

1/ Matsumoto (1960) gives 9 to 15 for 9 Western Pacific specimens and 16 to 18 for 20 from the central Pacific. Our two central Pacific specimens were from his lot of 20.

Table V

Selected meristic counts made on ten cleared and stained Auxis from the Eastern Pacific

Standard Length (mm)	First Dorsal Spines	Spines in Dorsal Interspace	Pectoral Rays	Gill Rakers, First Arch 1/	Vertebrae 2/ HA - HS - Total
13.2	XII	III	12	1-1-8	13-21-39
20.0	IX	V	20	4-1-19	13-21-39
21.5	X	VI	-	4-1-21	14-21-39
28.5	X	VII	-	6-1-25	14-21-39
33.3	XI	VI	24	9-1-31	14-21-39
39.4	XI	VI	24	9-1-31	15-21-39
41.5	XI	VI	24	9-1-32	14-21-39
43.7	XI	VI	23	10-1-32	17-21-39
88.9	XI	VIII	24	11-1-32	- - - -
89.0	X	VIII	22	11-1-33	20-21-39

[1/] Count always includes a central raker with roots into both the upper and lower limb.

[2/] Numbers correspond to vertebra upon which the first haemal arch, first haemal spine, and hypural occur.

In a 69 mm specimen the lateral line scales extended to beneath the second dorsal insertion. There were five rows above the lateral line with 22 scales in the longest of these which was immediately adjacent to the lateral line. Below the lateral line there were eight rows and the longest, again adjacent, contained 24 scales. The breast was scaled between the pectoral base and the isthmus and there were four rows of scales on each side of the first dorsal base. The remainder of the body and head was devoid of scales.

These observations show it would be futile to try to distinguish the species of Auxis by conventional taxonomic methods in most localities before they have attained adult characters. Several workers have intimated they could distinguish two species of Auxis based upon the juvenile color pattern (pigmentation) but proof has not been forthcoming. Matsumoto (1961), after examining pigmentation patterns and other characters on Hawaiian juveniles, sums up the situation quite well with the statement "Although the adults . . . are separable by corselet morphology, this character is useless for separating juveniles below 200 mm in length, because the corselet scales are not fully developed." Jones (1960) was no more successful in making specific determinations for juvenile Auxis in Indian waters.

4.4 Adult skeletal characters

Kishinouye (1923) made detailed anatomical studies on Japanese specimens of both frigate mackerels (his hira = thazard and maru = rochei) and pointed out differences in skeletal structures of the two. We were able to confirm the differences Kishinouye found and even discovered a few of our own; however, most of the differences were relative and not positive. Kishinouye gave as a specific character for the wide-corseleted species the absence of inferior foramens on the vertebrae. In the eastern Pacific material we skeletonized, inferior foramens were present in both species but in A. rochei they were fewer in number and more posteriorly placed.

The skull of A. rochei was narrower in proportion to length than that of the narrow-corseleted species. Measuring between the widest points of the pterotic processes and projecting this into the distance between the anterior margin of the vomer and the concave, ventral tip of the myodome's posterior aperture gave ratios of 1.37 to 1.40 for rochei and 1.29 to 1.38 for thazard.

The ethmoid of A. thazard was invariably diamond-shaped and had relatively straight margins on all four sides. That of the wide corseleted form, while basically identical in shape, had concave anterior margins and erratic (not straight) posterior margins. The anterior margins converged into a centrally produced, squared process.

These and several equally vague yet valid differences would serve to distinguish the two species should the need ever arise to identify skeletal fragments or stomach contents at the specific level. We were not able to find any differences between the eastern Pacific frigate mackerels and the same species from other localities.

5 SUMMARY

Internal and external anatomy and characters were examined, measured, compared and analyzed for 147 adult and numerous juvenile Auxis from world seas, primarily north of the equator. These studies showed there are only two valid species: Auxis thazard (Lacépède, 1802) which is confined to the Pacific and A. rochei (Risso, 1810) which is cosmopolitan in distribution.

A. thazard differs in many ways from rochei but the three most obvious characters that facilitate field recognition are a pattern of 15 or more oblique to nearly-horizontal dark wavy lines in the bare area on each side of the back, a corselet of scales along the lateral line that is at most three rows wide where it passes beneath the second dorsal fin, and a pectoral fin that extends past a vertical from the anterior margin of the patterned bare area on the back, (Fig. 1). In contrast, A. rochei has a dorsal pattern consisting of 15 or more broad, nearly vertical dark bars in the bare area on each side of the back, more than six rows of scales in the corselet where it passes beneath the second dorsal fin, and a pectoral fin that fails to reach a vertical beneath the anterior end of the dorsal scaleless area (Fig. 2).

6 ACKNOWLEDGMENTS

Many persons helped us in one way or another during the decade or more we devoted intermittent attention to the Auxis speciation problem. These individuals and their affiliations at the time of assistance are listed below. They include: M. Boeseman, and L.D. Brongersma, Rijksmuseum van Natuurlijke Historie, Leiden,

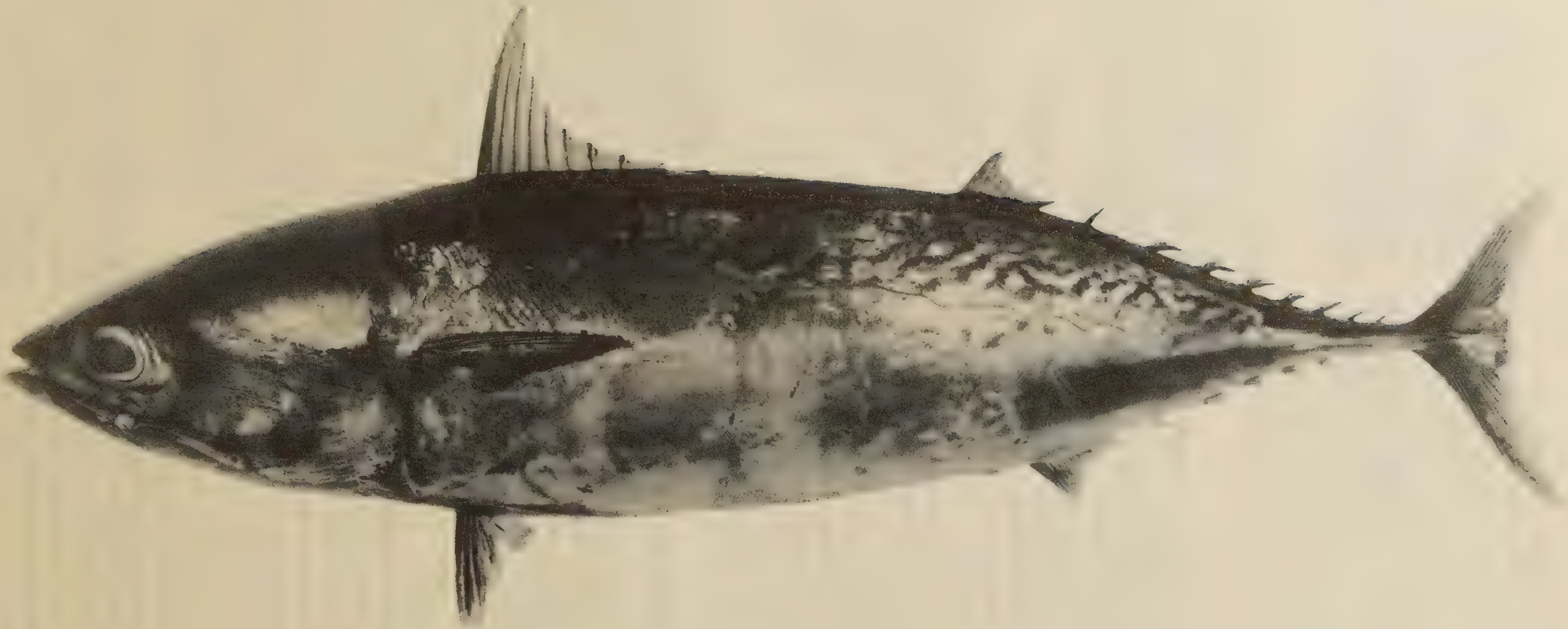

Fig. 1. *Auxis thazard* from the eastern Pacific. Collected at Morgan Bank, Baja California, October 6, 1949.

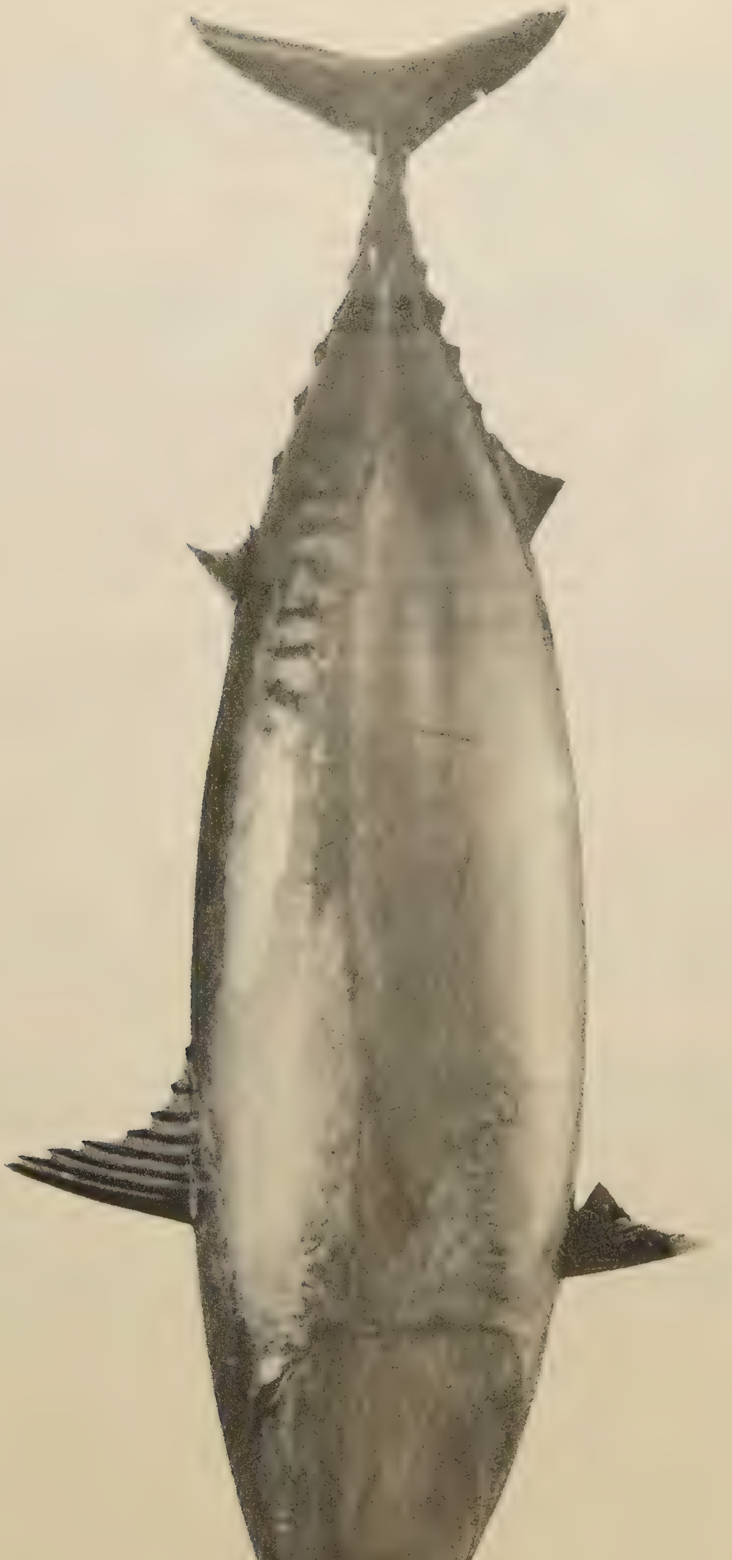

Fig. 2. *Auxis rochei* from near Santa Catalina Island, California, November, 1935. Photo by D. H. Fry, Jr.

who loaned us Bleeker's type of thynnoides and furnished invaluable information on Bleeker's specimens in that museum; C.M. Maldura and G. Brunelli, Laboratorio Centrale di Idrobiologia, Rome, who sent us three adult Mediterranean frigate mackerel, a series of juveniles, and gill arches from a number of sub-adults; Vernon E. Brock, Division of Fish and Game, Territory of Hawaii who obtained Hawaiian A. thazard for us; Carl L. Hubbs, Scripps Institution of Oceanography, La Jolla, who assisted us in making contacts with museum personnel, spent considerable time checking material in various museums, and offered invaluable counsel and guidance; Bell Shimada, Inter-American Tropical Tuna Commission, La Jolla, who loaned us data on and photos of Hawaiian Auxis; Donald Strasburg and Walter Matsumoto, U.S. Fish and Wildlife Service, Honolulu, who loaned us two of the Hawaiian wide-corseleted Auxis and sent details regarding the capture of several others; George S. Myers and Margaret Storey, Stanford Natural History Museum, who extended every possible courtesy while we examined Auxis in their collections; and Leonard P. Schultz, U.S. National Museum, who did the same at Washington.

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To these individuals, to the skippers and crew members of many fishing and research vessels, and to all others who helped us during the past decade or more we offer our heartfelt thanks.

Experience Paper No. 19

ALBACORE SCOUTING IN THE EASTERN NORTH PACIFIC OCEAN

By

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Abstract

California, being responsible for maintaining its natural resources and serving the people, has undertaken large-scale explorations that were beyond the ability of the fleet. The information gained from these cruises is maximized by combining many objectives -- basically, assisting the fleet and gathering management data.

In general, the 64 albacore surveys conducted by various agencies in the eastern north Pacific since 1917 fulfilled their basic objectives. The results of some were more dramatic than others but all contributed to our understanding of the resource. The surveys not only delineated the distribution of albacore, but at times were able to forecast changes in their migratory patterns which were useful to the fishery. These surveys also helped demonstrate migration patterns and the fish's response to environmental changes. Occasionally, new types of gear were tested to determine their potentials.

OPERATIONS DE RECONNAISSANCE POUR LA PECHE DE L'ALBACORE DANS LA PARTIE EST DU PACIFIQUE NORD

Résumé

L'Etat de Californie, à qui il appartient de veiller à la conservation de ses ressources naturelles et de servir l'intérêt public, a organisé des croisières d'exploration de grande envergure que n'auraient pu entreprendre les bâtiments de pêche commerciale. Les renseignements obtenus sont utilisés au maximum du fait de la multiplicité des objectifs - il s'agit essentiellement de seconder l'activité de la flottille de pêche et de rassembler des données sur l'exploitation rationnelle des pêcheries.

Dans l'ensemble, les 64 croisières de recherche sur l'albacore menées depuis 1917 par divers organismes dans la partie est du Pacifique Nord ont atteint leurs objectifs de base. Certaines ont donné des résultats plus spectaculaires que d'autres, mais toutes ont contribué à accroître les connaissances sur les ressources en albacores. Ces croisières ont permis non seulement de délimiter les aires de répartition géographique des albacores, mais parfois de fournir aux pêcheurs d'utiles prévisions des variations dans les mouvements migratoires. Elles ont également contribué à mettre en évidence la structure des migrations et les réactions des poissons aux modifications du milieu. Elles ont aussi fourni l'occasion de procéder, de temps à autre, à des essais d'efficacité de nouveaux types d'engins de pêche.

RECONOCIMIENTOS SOBRE LA ALBACORA EN EL PACIFICO NORORIENTAL

Extracto

Asumiendo la misión de conservar sus recursos naturales para ponerlos a disposición del pueblo, California ha emprendido exploraciones en vasta escala que superan las posibilidades de su propia flota. La combinación de múltiples objetivos revaloriza la información recogida con estos cruceros de reconocimiento, objetivos que consisten, fundamentalmente, en ayudar a la flota y acopiar datos.

Por lo general, los sesenta y cuatro reconocimientos efectuados por diversos organismos en el Pacífico nororiental desde 1917, han cumplido sus objetivos fundamentales. Los resultados han sido más sorprendentes en unos casos que en otros, pero todos han contribuido a un mejor conocimiento de los recursos. No sólo delimitan estas exploraciones la distribución de la albacora, sino que a veces han permitido pronosticar modificaciones en sus hábitos migratorios, con utilidad para la explotación pesquera. También han coadyuvado a revelar modalidades de las migraciones y las reacciones de esta especie a los cambios de ambiente. De vez en cuando se han ensayado nuevos tipos de artes o aparejos para determinar sus posibilidades.

1 EXPLORATORY FISHING

In actuality, exploration is an integral part of every fishing venture, sport as well as commercial. Negative results for the sportsman mean an empty creel and some ribbing but he has a day's recreation as consolation for his efforts. The commercial fisherman has a great deal more at stake, for his livelihood as well as his ventured capital are dependent upon his degree of success. The cost of initial exploration is high, and few are willing to undertake it alone -- yet several do each season. In common practice, small groups of fishermen search together for the season's first albacore and as the season progresses the entire fleet may fan out to relocate fast-moving schools, thus minimizing risk and maximizing potential gain.

California, being responsible for maintaining the resource and serving the people, undertakes large-scale explorations that are beyond the ability of the fleet. The information gained from these cruises is maximized by combining many objectives into each expedition. Thus, the various eastern north Pacific coastal states and the federal government not only send vessels scouting for albacore to assist the fleet but also attempt to gain as much knowledge as possible to help carry out their conservation responsibilities.

Exploration, as a tool of research, yields many vital pieces of information which otherwise would be difficult if not impossible to obtain. For example, migration routes can be traced; areas of abundance or scarcity can be delineated; environmental observations can be made to reveal ecological relationships; and laboratory specimens can be procured for life-history and other studies.

The problems pertaining to exploratory fishing are not unique; they are closely akin to other oceanographic field endeavors. The explorer with a limited budget and an incomplete technology basically would like to know everything at once! He needs to know where, when, why and how about the species in question along with details on the food chain, the environment and population dynamics.

That only one vessel is available for most surveys tends to emphasize the compromises that must be made in fishing gear and in types of hydrographic observations. To answer such a seemingly simple question as what is the range of a fish, the biologist must pick and choose from a variety of gear which frequently is mutually exclusive in its use: trolling lines, gill nets, encircling nets, longlines and trawls. To obtain a comprehensive picture of the environment requires the full time of one or more vessels. Thus obtaining environmental observations frequently is resolved by making those most easily attained (surface water temperatures) or those most easily processed (salinities and bathythermograph casts).

Utilizing more than one vessel is an obvious method to increase the breadth and scope of a survey. At one time or another and with several variations, this approach was used to good advantage in the albacore surveys in the eastern north Pacific.

2 EASTERN NORTH PACIFIC ALBACORE SURVEYS

2.1 Background

Since the first albacore scouting cruise in 1917 (Table I), various governmental agencies of the United States and Canada have fielded 64 expeditions in the eastern north Pacific Ocean. At the basic field level, 39 technical people participated in the observations and fishing activities which were conducted from 26 different vessels utilizing 6 distinct types of gear in at least a dozen different ways. Some of the trips were during the height of the run (July, August, and September) while others were in the "off-season." Biological and environmental observations also varied widely, ranging from very little data to extensive biological notes and full-scale hydrographic stations. Many of the data regarding these cruises were recorded and filed away; a few were summarized in some detail and received limited circulation, and fewer still were published. The data from individual expeditions are spotty and discontinuous but as a collection appear of sufficient continuity to be of interest to fishermen, to industry, and to fellow researchers. Since individual cruise details are either in print or soon will be, the author will present only highlights of the trips and report some of the significant factors gleaned from them.

The strongest thread of continuity in all the surveys has been an expressed or, at times, implied two-fold purpose: to develop the fishery for greater exploitation and to gain scientific knowledge essential for managing the resource.

Table I

Synopsis of albacore surveys in the eastern North Pacific Ocean

Year	General Area Surveyed	Sponsoring Agencies	No. of trips	Fishing Gear	Remarks	References
1917 1918	Southern California coastal and offshore waters.	California Dept. Fish and Game	7	Trolling Longlines Gill nets	Working along side the commercial fleet and alone, took albacore in almost every month of the year; 1st use of longlines in area. First effort to systematically collect environmental data with catch.	Pinkas, (ms)
1933 1937	Central and Southern California coastal waters, occasionally offshore.	California Dept. Fish and Game	7	Trolling	Made short exploratory cruises on fishery patrol boats. . Many trips undertaken during period of albacore scarcity in eastern Pacific. Few albacore were taken though conditions appeared favorable.	Pinkas, (ms)
1939 1941	Northern Baja Calif., California, Oregon and Washington coastal and offshore waters.	California Dept. Fish and Game	3	Trolling	Beginning of large scale surveys. Pre-season cruises, May-June 1939-1941, failed to locate albacore. Mid-season efforts, 1939-41, located and delineated areas of abundance.	Pinkas, (ms)
1948	British Columbia coastal waters.	Fisheries Research Board of Canada	2	Trolling Longlines	Using two fishery patrol vessels located albacore and placed the commercial fleet on unexploited schools.	Scagel (1949)
1948 1949 1950	Central and Eastern North Pacific Ocean and California coastal and offshore waters.	California Dept. Fish and Game	10	Trolling Pole & line Gill nets	Post-World War II resumption of albacore field investigations. Located and delineated areas of albacore abundance, none found in central Pacific Ocean though. Released tagged albacore but no recoveries.	Godsil & Greenhood, (1952) Pinkas, (ms)

Table I (cont'd)

1949 1950 1951 1952	Oregon, Washington and Southeastern Alaska coastal and offshore waters.	U.S. Fish & Wildlife Service, Seattle, Washington	4	Trolling Longlines Gill nets	1949-Located schools of albacore. 1950-Located, delineated and traced the movement of schools, released a few tagged albacore. 1951 and 1952-First albacore encountered mid-June about 500 miles W of Trinidad Head, Calif.	Powell & Hildebrand (1950) Powell, Alverson, Livingstone, (1952) Schaefers (1952, 1953)
1954 1955	Northern Baja Calif., and Southern California coastal and offshore waters.	California Dept. Fish and Game	4	Trolling Longlines	Cruises made simultaneously with U.S. Fish and Wildlife Service explorations in central Pacific and oceanographic survey NORPAC. 1954-Winter cruise found only one fish. 1955-Pre-season (May) cruise found deep swimming albacore in offshore waters, apparently the first migrants of the season. 1955-Mid-season (Aug.) cruise located and delineated concentrations of albacore.	Pinkas (ms)
1955	Oregon and Northern California offshore waters.	U.S. Fish & Wildlife Service, Hawaii	1	Trolling Longline	May to Sept., in conjunction with other cruises in central Pacific, found a discontinuous distribution of albacore, with concentrations in the eastern and central Pacific.	Graham (1957)
1955 1956	Washington, Oregon and Northern California coastal and offshore waters.	University of Washington, Dept. of Oceanography Oregon Fish Commission	2	Trolling	1955-June-July, cruise crossed the surface transition zone of rapid temperature change penetrating into the eastern Pacific central water mass, only two albacore were taken, temperature range 57° to 63° F. 1956-Report of results not seen.	Holmberg (1955, 1956) Love, (1955) Frolander & Lincoln (1956)

Table I (cont'd)

1956	Oregon, Washington and British Columbia 50 to 800 miles offshore.	U.S. Fish & Wildlife Service, Seattle	1	Trolling Gill nets	July-Aug., cruise took albacore with both types of gear 80 to 600 miles offshore in area bounded by Lat. 42° to 49° N and Long. 126° to 140° W	Anonymous (1956)
1957	Washington, Oregon and Northern California, 50 to 300 miles offshore	U.S. Fish & Wildlife Service, Hawaii	11	Trolling Longline Gill nets	June to Aug., chartered vessels located and delineated concentrations of albacore. USFWS vessels made pre-season survey and verified catches of boats. Found albacore throughout area, concentrations were spotty.	Graham (1959)
1957 1958	Northern Baja Calif., and Southern California coastal and offshore waters.	California Dept. Fish and Game	2	Trolling Longline	1957 scouting interrupted by operational difficulties such as weather. Part of cruise devoted to albacore tagging. 1958 scouting hampered by weather. No albacore taken.	Mais (1957) Craig (1958)
1959	Northern Baja Calif., to Central California offshore waters.	California Dept. Fish and Game U.S. Fish & Wildlife Service, Hawaii	2	Trolling Longlines Live Bait Gill nets	June cruise fround the first albacore of the season north of Lat. 32° N and east of Long. 130° W and within the 58° to 62° F isotherms.	Craig & Graham (1961) Graham & Craig (1961)
1959	Oregon, 40 to 140 miles offshore.	Oregon Fish Commission	1	Trolling	July, found albacore in area bounded by Lat. 42° to 44° N and Long. 125° to 127° W Released tagged albacore.	Ayers (1959)
1960	Northern Baja California to Central California primarily offshore to 134° W. Long.	California Dept. Fish and Game U.S. Fish & Wildlife Service, San Diego	1	Trolling	May-June, located pre-season albacore in the water mass of the California Current system, temperature range 59.5° to 64.2° F and salinities of 32.95 to 33.53 ppm.	Craig & Caneday (1962)

Table I (cont'd)

1960	Oregon 40 to 140 miles offshore.	Oregon Fish Commission	1	Trolling	June-July, located small scattered groups of albacore between Lat. 42° to 45° N and Long. 126° to 127° W. Generally unfavorable temperatures in area surveyed.	Ayers (1960)
1961	Northern Baja Calif., and Central California primarily offshore to 134° W long.	California Dept. Fish and Game U.S. Fish & Wildlife Service, San Diego	3	Trolling	May-June, three vessels participated. Only albacore found were 150 miles southwest of Pt. Conception.	Craig (1961) Mackett (1961) Anonymous (1961)
1961	Washington and Oregon offshore waters to 132° W long.	U.S. Fish & Wildlife Service, Seattle and San Diego	1	Trolling Gill nets Pelagic trawl	July-Aug., located albacore between Lat. 42° to 46° N and Long. 125° to 132° W. Rough weather interrupted survey. Pelagic trawl did not take albacore, trolling and gill nets did.	Anonymous (1961)
1961	Oregon 40 to 140 miles offshore.	Oregon Fish Commission	1	Trolling	June-July, located small groups of albacore between Lat. 42° to 45° N and Long. 126° to 127° W. Released tagged albacore. Favorable temperatures throughout survey area.	Ayers (1961)

Total Trips 64+

2.2 First surveys - 1917-1918

Under the guidance of W.F. Thompson, the California Fish and Game Commission made an excellent start toward resolving the mysteries of the albacore in 1917 and 1918. Field work was conducted by two Japanese fishery experts utilizing trolling lines, gill nets, and longlines -- the latter gear being new to the eastern Pacific fleet. They succeeded in taking albacore at various depths and in almost every month of the year; however, the 1917 season was odd or different in that the commercial catch peaked in November and December, three to four months later than normal. We now know that these "off-season" catches were from residual groups of fish. The Japanese specialists made environmental observations which included surface and subsurface water temperatures, water current measurements and meteorological notes. Their records of catch and temperature revealed that albacore will tolerate a temperature range as great as 13.4° to 22.2° C. (56° to 72° F.) but prefer a narrower band between 15.6° and 20.9° C. (60.1 to 69.6° F) (Pinkas, ms).

2.3 The 1930's and early 1940's

Scouting by governmental agencies languished until the early 1930's when California reactivated its program in the form of short, one - to several-day sorties by patrol craft. This was done toward the end of the period of albacore scarcity which started in 1927. Although surface water temperatures were favorable, few fish were found.

With the commissioning of the research vessel N.B. SCOFIELD in 1939, the California Department of Fish and Game initiated a new era of research. Intensive and extensive work covered most of the albacore's known eastern north Pacific range, north to Washington and south into Baja California, Mexico. Fishing only in the surface waters, pre-season efforts failed to find albacore but the mid-season cruises located and delineated areas of abundance. Surface water temperatures and other ecological factors were noted and recorded. The Second World War brought the work to an abrupt halt late in 1941 (Pinkas, ms).

2.4 Post World War II period, 1948-1952

The Second World War's disruptive influence was felt as long as three years after cessation of hostilities. Not until 1948 were governmental agencies able to amass enough men and equipment to resume full-scale albacore field investigations.

In the period 1948 through 1952, over 14 cruises were fielded by the California Department of Fish and Game, the U.S. Fish and Wildlife Service, and the Fisheries Research Board of Canada; California alone sponsored 10. The increased activity included gear experiments (longlines and gill nets) and exploration beyond the usual fishing areas. Longlines made a poor showing, taking only a few albacore. Gill nets proved more successful than longlines but not as efficient as conventional trolling lines. One serious limitation, particularly in terms of potential commercial exploitation, was the relatively high rate, 25 percent, of physical damage sustained by netted albacore.

Three of these 14 expeditions made noteworthy contributions. California's extensive search in 1948 in the central and eastern north Pacific located albacore up to several hundred miles off the Washington, Oregon, and California coasts but found none in the central north Pacific (Godsil and Greenhood, 1952). Canada, also in 1948, utilized two fishery patrol craft to locate albacore and place their commercial fleet on unexploited schools (Scagel, 1949). In 1950, the U.S. Fish and Wildlife Service vessel JOHN N. COBB located albacore far at sea and traced their movements as they approached the coasts of Oregon and Washington (Powell, Alverson, and Livingstone, 1952).

2.5 The two years 1954-1955

California's 1954 winter and spring longline-fishing cruises were coordinated with expeditions fielded by the Pacific Oceanic Fishery Investigation, U.S. Fish and Wildlife Service, in Hawaii. Utilizing longlines to sample the subsurface waters and trolling lines for the surface, large sections of the central and eastern north Pacific were explored. The one albacore taken at latitude 24° 03'N longitude 132° 04'W appeared to be a straggler. Wide-spread throughout the subsurface waters were bigeye tuna, Parathunnus sibi, Pacific lancetfish, Alepisaurus richardsoni, and blue sharks, Prionace glauca -- the latter in greatest abundance.

Pre-season 1955 cruises by California and the University of Washington (the latter in a joint venture with the Oregon Fish Commission), succeeded in locating only a few albacore several hundred miles offshore. These fish, which appeared to be the forerunners of the main body, were not abundant enough for commercial exploitation. Bigeye tuna were taken in fair numbers along longitude 135° W between latitudes 29°

and 32° N. Blue sharks and bonito sharks, Isurus glaucus, were caught throughout the area but not as abundantly as in 1954.

Three of the 1955 surveys were conducted partially or entirely during a period of intensive oceanographic research. NORPAC, a quasi-synoptic hydrographic survey of the entire north Pacific Ocean, was fielded in August, a month of peak commercial albacore fishing. Recent publication of NORPAC's data and results has made it possible to synthesize a comprehensive picture of the albacore resource and its environment during that year. Preliminary results of the August survey conducted by the California Department of Fish and Game from the Scripps Institution of Oceanography vessel PAOLINA T showed that subsurface albacore appeared to be concentrated (9.5 albacore per 100 hooks) in a narrow band of water bounded by latitudes 31° and 32° N and extending westward from the coast to longitude 122° W the outermost limit of the survey. The surface distribution of albacore, determined by trolling and noting visual schools, was different from their subsurface distribution. In only one small area, latitude 31° 00'N, longitude 117° 07' W, did a concentration of fish manifest itself.

2.6 From 1957 to the present

The 1957 work is notable for its finite coverage of a relatively broad area: nine chartered commercial boats, two research vessels, and four governmental agencies participated in the search and observations. The results have been summarized in a data report (Graham, 1959) and partially analyzed (McGary, Graham and Otsu, 1961). Albacore were found throughout the area surveyed, roughly from 50 to 300 miles offshore between the latitudes of Point Conception, California, and Grays Harbor, Washington (35° to 47° N). Numerous pockets of concentrated fish (catch rate 21 albacore per 100 troll-line hours) were encountered within the 15.5° to 18.5° C isotherms (60° to 65° F). This broad coastal band of fish was encompassed by the survey vessels north of latitude 40° N but its western boundry between latitudes 35° to 38° N was not determined. This concentration of fish probably extended westward for some distance.

Troll lines, the principal gear used by all the vessels in the survey, took most of the fish. The U.S. Fish and Wildlife Service vessel JOHN R. MANNING also utilized longlines and gill nets: longlines took but a single albacore although 149 were netted. The gill nets also captured a significant number of pomfrets, Brama rayi (some at every station), and blue sharks (which were concentrated between longitudes 126° 50' W and 128° 40' W and latitudes 38° 45' N and 43° 45' N).

Since 1957, there has been an average of two or more cruises per year. Although the expeditions have not been as extensive as in the past, the agencies channeled their efforts into cooperative cruises. The results of most of these have been published or are in the process of publication (Craig and Graham, 1961; Graham and Craig, 1961; Craig and Caneday, 1962). In general, the results have amplified previous findings and have shed light on some of the causes for seasonal fluctuations. Of note was the early detection of a more northerly orientation of the albacore during the warm-water years 1957-59. This information was passed on to the commercial fleet early enough to save them many thousands of dollars in exploration costs.

The U.S. Fish and Wildlife Service tried capturing albacore with a mid-water trawl in 1961 but was unsuccessful.

3 DISCUSSION

3.1 Aid to the fleet

3.1.1 Direct assistance

In terms of direct, positive assistance to the albacore fishery, most of the expeditions fell short of their goal. Cruises that did aid the fishermen were both dramatic and rewarding. For example, Canada's effort in 1948 put the fleet on unexploited albacore schools while California's pre-season scouting and accurate predictions in 1959 and 1960 saved the fleet hundreds of hours in running and scouting time.

3.1.2 Indirect benefits

Indirect benefits, i.e. scientific knowledge gained during the explorations, are only now becoming usable. California's pre-season predictions are due largely to the wealth of information obtained during these cruises.

We now know why it has not been possible to extend the season. We know that the principal albacore population is not in the eastern north Pacific in the off-season, although stragglers or remnant groups may overwinter.

We can now explain the sporadic occurrence of albacore off Oregon, Washington, and British Columbia. The movement of fish in this area was clearly demonstrated in 1950 by the cruise of the JOHN N. COBB, when albacore were located far at sea and were followed shoreward and northward as favorable water temperatures developed (15.0° to 18.4° C.).

Other problems and questions pertaining to the albacore fishery will be answerable as the data undergo further analyses.

3.2 Survey techniques

3.2.1 Gear

The best choice of gear at the onset of an exploratory fishing program is the type in current use by local commercial fishermen. This was graphically demonstrated by the results of the albacore surveys of the eastern north Pacific wherein trolling lines accounted for most of the albacore taken.

To use other than conventional gear without adequate tests and evaluation tends to becloud the results. Many of the expeditions assumed this risk because of limitations in time and money and the lure of quick, spectacular results. To determine if albacore occupy depths other than the surface waters it was necessary to resort to longlines and gill nets, yet there were no conversion factors to equate their efficiency with trolling lines or with each other. On one cruise, gill nets were more efficient for capturing albacore than were longlines, (JOHN R. MANNING, cruise 1957), yet the Japanese utilize the latter gear very effectively. To complicate the problem, gill nets fished off southern California were not as productive as those used farther north (1950 cruises). The reasons for these differences have not been discerned from the available data.

3.2.2 Scope of surveys

The scope of a survey should be roughly proportional to the size of the resource if it is to achieve its basic objectives in the shortest time at the lowest cost. This is almost impossible to attain at the beginning; however, as new information comes to light, the project should be tailored accordingly -- either contract or expand activities as the situation warrants. There are several examples among the north Pacific albacore explorations.

California's survey of the entire eastern north Pacific in 1941 apparently developed as a result of the more modest expeditions in 1939 and the early 1930's. Although exploratory work was interrupted by the Second World War, its reactivation in 1948 continued the earlier pattern of trying to encompass the resource -- the N.B. SCOFIELD traversed half the north Pacific Ocean and spanned the albacore's known range in the eastern Pacific toward achieving this goal.

Two U.S. Fish and Wildlife Service sponsored cruises illustrate the effectiveness of survey scope in other veins. In 1950, the JOHN N. COBB set out in June to gain a better understanding of albacore behavior off the coasts of Oregon and Washington. They "stayed" with the problem until October and were thus able to fulfill their objectives. Conversely, a recent cruise failed to achieve its goal of locating the first albacore of the season because of time limitations. Albacore like many other fish species simply are not aware of man-made schedules.

In 1957 the U.S. Fish and Wildlife Service approached the problem of albacore distribution by fielding 11 vessels simultaneously over a broad sector of ocean. This yielded data unobtainable by other means. Although initially expensive, it probably costs less per unit of information gained than other methods.

Along with adequate field coverage, organizations conducting fishery surveys should publish all results, conclusions, and recommendations as soon as possible. One of the greatest weaknesses of the early albacore work has been a failure to publish results. Typical examples are California's surveys of 1917-18, 1941, and the 1950's. In recent years, most agencies have rectified this omission.

3.2.3 Future surveys

Many questions about the albacore resource remain either unanswered or only partially answered: seasonal migration routes, seasonal variation in occurrence and abundance, location of spawning areas and nursery grounds, identification of larvae, the size of the population, the degree of exploitation by various fleets, etc., to name a few. Some of these problems probably can and will be solved by exploratory fishing.

4 SUMMARY

Governments sponsor albacore exploration to gain scientific knowledge for the maintenance of the resource and to aid their fisheries when necessary.

In general, the 65 albacore surveys conducted in the eastern north Pacific since 1917 fulfilled their basic objectives of locating fish and gathering management data. The results of some were more dramatic than others but all contributed to our understanding of the resource. The surveys not only delineated the occurrence of albacore but at times were able to forecast changes in their distribution which was useful to the fishery. These surveys also helped demonstrate migration patterns and the fish's response to environmental changes. Occasionally new types of gear were tested to determine their potential in the fishery.

Future surveys will be necessary because as yet we do not have all the information required for intelligently exploiting and managing the resource. These expeditions should be of sufficient scope and breadth to encompass the entire resource or the effort will be dissipated in redundant work yielding little additional knowledge.

Experience Paper No 20

A METHOD OF SAMPLING THE PACIFIC ALBACORE (Thunnus germo) CATCH FOR RELATIVE AGE COMPOSITION

By

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Abstract

Double sampling is compared to simple random sampling for determining relative age composition of Pacific albacore landings. Sample size equations for a minimum variance with fixed sampling costs under proportional allocation are given. Double sampling was more efficient than simple random sampling for the given unit costs of ageing and measuring fish.

METHODE D'ECHANTILLONNAGE DES PRISES D'ALBACORES (Thunnus germo) DU PACIFIQUE EN VUE DE LA DETERMINATION DE LA STRUCTURE PAR AGE

Résumé

On compare les méthodes du sondage stratifié et du sondage aléatoire simple permettant de déterminer la structure par âge des albacores du Pacifique d'après les quantités débarquées. La communication fournit des équations relatives à la taille de l'échantillon pour une variance minimale et pour un coût d'échantillonnage donné, selon la méthode de stratification avec répartition proportionnelle. Pour les coûts unitaires donnés de détermination de l'âge et de la taille des poissons, le double échantillonnage s'est révélé plus efficace que l'échantillonnage simple.

TOMA DE MUESTRAS DE LAS CAPTURAS DE ALBACORA DEL PACIFICO (Thunnus germo) PARA DETERMINAR SU COMPOSICION RELATIVA POR EDADES

Extracto

Se establece una comparación entre los méthodos de doble muestreo y muestreo simple aleatorio para determinar en los desembarques de albacora del Pacífico su composición relativa por edades. Se dan ecuaciones de la dimensión de la muestra para una variancia mínima con costos fijos de muestreo, según una distribución proporcional. Para los costos dados por unidad de peces muestra, el método de doble muestreo resultó más eficaz que el simple al azar.

1 INTRODUCTION

With the development of an aging technique for Pacific albacore (Thunnus germo) by Bell (1962), that utilizes scales as indicators of age, a sampling program was initiated by marine scientists of the California Department of Fish and Game to estimate the age composition of the California albacore landings.

In this paper the author will present a basic outline of the sampling design and some preliminary evaluations of the procedure.

The objective of the sampling program is to estimate the relative age composition of the "log fleet" landings of albacore each season. The "log fleet" is defined as fishing boats whose crews supply the California State Fisheries Laboratory with a record or log of each fishing trip. This also is the segment of the fleet for which catch-effort data are available. The relative age composition and catch data are used to form an absolute age composition of the yearly landings. This information can lead to measures of relative abundance for each age group being exploited in the fishery and hence, to total mortality estimates.

The double sampling design was used during the 1961 season. Its use for age composition in California was first described by Kutkuhn (n.d.). He used the design to estimate absolute age composition of California salmon landings. His manuscript describing the salmon sampling program provided the idea for testing the double sampling scheme to estimate the relative age composition of the albacore catch.

2 CHOICE OF SAMPLING DESIGN

2.1 Simple random sampling

To design a program that would estimate relative age composition, we had to decide which of several sampling methods would lead to an estimate with a reasonably low variance. One choice is to estimate the proportion of each age group in the catch by using age determinations from a simple random sample of fish.

2.2 Stratified sampling

Another method, stratified sampling with proportional allocation, is more efficient than simple random sampling. The variance of an estimate from proportional stratified sampling can be no larger than the variance obtained through simple random sampling. The degree of efficiency depends on how much difference exists between strata for the character under question. That is, if the population is divided into units which are homogeneous for the character under investigation, a more efficient estimate, compared to simple random sampling, of the mean of that character is formed by:

(1) obtaining the estimate from each unit or stratum;
(2) weighting the estimate by the stratum size; and
(3) summing the weighted estimates of all strata.

The greater the difference between strata for the character under investigation, the more efficient stratified sampling will be when compared to simple random sampling.

2.2.1 Stratifying the "log fleet" catch

Stratifying the population or "log fleet" catch on the basis of a character that will give known strata sizes and sufficient heterogeneity of age composition between strata is not possible. However, one can stratify a sample of that population by length, which is considered closely correlated with age, and let the relative length frequencies in the sample be the strata weights. Thus, from a simple random sample of size n, the population stratum weight $\frac{N_i}{N}$ is estimated by $\frac{n_i}{n}$, where N_i and n_i are the numbers of fish in length stratum i in the population and sample respectively. We now have to estimate the relative age composition in each stratum, weight the estimates by $\frac{n_i}{n}$, and sum the estimates of the strata. This method allows taking a cheaper preliminary sample to stratify the population and a secondary sample for the character being investigated and is called double sampling or two-phase sampling for stratification.

In addition to stratifying by length, the catch was stratified by port and month of catch to compensate for possible space-time variability in age composition.

The strata are:

(1) Port of landing

  (a) San Diego
  (b) Los Angeles
  (c) Monterey-San Francisco
  (d) Eureka

(2) Month of catch

The number of fish caught (i.e. stratum weights) by the "log fleet" in each port-month stratum is known.

The double sampling design was used by the Department during the 1961 fishing season. Within a port-month stratum a simple random sample of fish was measured and every tenth fish was aged. The length frequencies together with the age determinations were then used to estimate the relative age composition of the "log fleet" landings within each port-month stratum.

At this point it may be well to introduce some notation that will aid in understanding the sampling design.

3 NOTATION AND DEFINITIONS

The notation used for the various measurements and estimates refers to a quantity within a particular port-month stratum. No provision by way of a subscript for a particular port-month stratum is presented.

n = the number of fish sampled for length.

n_i = the number of fish sampled for length that fall into the i^{th} length stratum, $(i=1,\ldots,L)$.

a = the total number of fish aged.

a_i = the number of fish aged in length stratum i.

a_{ij} = the number of fish in length stratum i, and age stratum j, $(j=1,\ldots,K)$.

From these definitions the following relations hold:

$\frac{n_i}{n} = p_i$ the proportion of the sample in i^{th} length stratum.

$$\sum_{i=1}^{L} n_i = n$$

$$\sum_{j=1}^{K} a_{ij} = a_i$$

$$\sum_{i=1}^{L} a_{ij} = a_j$$ the number of fish sampled in age stratum j.

$$\sum_{i=1}^{L} \sum_{j=1}^{K} a_{ij} = \sum_{i=1}^{L} a_i = a$$

$$\frac{a_{ij}}{a_i} = p_{ij}$$ the proportion of age stratum j fish in the i^{th} length stratum.

$$q_{ij} = 1 - p_{ij} .$$

An unbiased estimate for the proportion of age stratum j fish in the population is

$$P_j = \sum_{i=1}^{L} p_i p_{ij} . \tag{1}$$

3.1 Variance of the estimates

The variance of P_j, ignoring finite population corrections, is estimated by:

$$\text{Var } P_j \approx \sum_{i=1}^{L} \frac{p_i^2 \left(p_{ij} q_{ij} \right)}{a_i} + \sum_{i=1}^{L} \frac{p_i \left(p_{ij} - P_j \right)^2}{n} . \tag{2}$$

The first term on the right of (2) is the component of the variance due to the differences within strata, while the second term on the right is that portion of the variance due to the between-stratum variation.

Equation (2) holds true for any allocation of the sample for ages. During the 1961 season, the second phase sample for ages was a simple random sample of the population. When the number sampled for age within a length stratum is proportional to the number measured,

$$\frac{n_i}{n} = \frac{a_i}{a} \tag{3}$$

and

$$a_i = p_i a . \tag{4}$$

Substituting the results of (4) for a_i in equation (2) we have for the variance of the estimate under proportional allocation:

$$\text{Var } P_j \approx \sum_{i=1}^{L} \frac{p_i \left(p_{ij} q_{ij} \right)}{a} + \sum_{i=1}^{L} \frac{p_i \left(p_{ij} - P_j \right)^2}{n} . \tag{5}$$

The estimates of the relative age composition and variances of the estimates for two

Table I

Relative Age Composition and Estimated Variance of P_j for Two Months at Los Angeles

		DOUBLE SAMPLING		SIMPLE RANDOM SAMPLING	
	AGE GROUP	RELATIVE AGE COMPOSITION P_j	ESTIMATED VARIANCE OF P_j	RELATIVE AGE COMPOSITION P_j	ESTIMATED VARIANCE OF P_j
JULY	I	0.049	0.00009293	0.068	0.00019419
	II	0.318	0.00046196	0.320	0.00066954
	III	0.593	0.00047892	0.563	0.00075699
	IV	0.039	0.00011059	0.049	0.00014402
AUGUST	I	0.045	0.00007351	0.085	0.00039260
	II	0.124	0.00033224	0.121	0.00053295
	III	0.708	0.00082085	0.668	0.00111387
	IV	0.121	0.00052397	0.121	0.00053295
	V	0.003	0.00000981	0.005	0.00002513

port-months, for double sampling and simple random sampling, are shown in Table I. In each case, as might be expected, the variances of double sampling are lower than those of simple random sampling. In some cases, such as the I age group in both port-month strata, the reduction in variance is quite substantial, in others such as the IV age group in August the reduction in variance due to stratification is almost negligible. If in a choice between two sampling designs the reduction in variance was the only criterion, double sampling would be the choice. However, considerable expense is involved in obtaining the preliminary length sample and the question arises as to the value of the length information in reducing the variance. Certainly, the money spent taking the preliminary length sample could be allocated to drawing a larger simple random sample for ages, which would also reduce the variance.

4 CHOICE OF A SAMPLING DESIGN WITH A FIXED COST

We can consider the problem to be one of choosing, for a fixed cost, (1) double sampling, or (2) simple random sampling without stratification. Solving the problem entails three steps:

a) determining the sample sizes needed for a minimum variance for a fixed cost in each of the two procedures;
b) obtaining the variances of the estimates for the two designs, using the sample sizes computed to give the minimum variance; and
c) comparing the two variances.

4.1 Sample sizes needed for minimum variance with fixed costs

For a fixed cost the size of a single sample of simple random sampling will be the fixed cost C_0 divided by the unit cost of collecting and aging a fish, thus:

$$a = \frac{C_0}{c_1} \qquad (6)$$

where c_1 is the cost of collecting and aging one fish.

The sample sizes for double sampling are more complicated. In this case a cost function of the form

$$C_0 = c_1 a + c_2 n \qquad (7)$$

is introduced, where c_1 and c_2 are the costs of aging and measuring a fish respectively.

The problem is to choose an a and n such that the variance will be a minimum, subject to the cost condition.

We may rewrite the expression for the variance given in (5) as

$$V = \frac{V_a}{a} + \frac{V_n}{n} \qquad (8)$$

where

$$V_a = \sum_{i=1}^{L} p_i \, p_{ij} \, q_{ij}$$

and

$$V_n = \sum_{i=1}^{L} P_i \left(P_{ij} - P_j \right)^2 .$$

If we form the equation

$$Y = \text{Var } P_j + \mu C_0 , \tag{9}$$

and substitute into (9) the quantities from (7) and (8), we have:

$$Y = \frac{V_a}{a} + \frac{V_n}{n} + \mu \left(c_1 a + c_2 n \right) \tag{10}$$

or

$$Y = \frac{V_a}{a} + \frac{V_n}{n} + \mu c_1 a + \mu c_2 n \tag{11}$$

where μ is some constant.

We may write this as:

$$Y = \left(\frac{\sqrt{V_a}}{\sqrt{a}} - \sqrt{\mu c_1 a} \right)^2 + \left(\frac{\sqrt{V_n}}{\sqrt{n}} - \sqrt{\mu c_2 n} \right)^2 + 2\sqrt{V_a c_1 \mu} + 2\sqrt{V_n c_2 \mu} \tag{12}$$

Now, it is possible to write (12) as:

$$Y = \text{Var } P_j + \mu C_0 = \left(\frac{\sqrt{V_a}}{\sqrt{a}} - \sqrt{\mu c_1 a} \right)^2 + \left(\frac{\sqrt{V_n}}{\sqrt{n}} - \sqrt{\mu c_2 n} \right)^2 \tag{13}$$

+ terms independent of n and a.

From (13) we can see that the variance of P_j is a minimum for a fixed C_0 or that C_0 is a minimum for a fixed variance when each of the squared terms on the right side are zero. That is, when

$$a = \frac{\sqrt{V_a}}{\sqrt{\mu c_1}} \tag{14}$$

and

$$n = \frac{\sqrt{V_n}}{\sqrt{\mu c_2}} \tag{14a}$$

Substituting from (14) and (14a) into the cost function (7) we have

$$\frac{1}{\sqrt{\mu}} = \frac{C_0}{\sqrt{V_a c_1} + \sqrt{V_n c_2}} \tag{15}$$

From (14) and (15)

$$a = \frac{\sqrt{V_a}}{\sqrt{c_1}} \cdot \frac{C_0}{\sqrt{V_a c_1} + \sqrt{V_n c_2}} \tag{16}$$

and

$$n = \frac{\sqrt{V_n}}{\sqrt{c_2}} \cdot \frac{C_0}{\sqrt{V_a c_1} + \sqrt{V_n c_2}} \tag{17}$$

Now that we have the values of a and n that will minimize the variance of the proportion for a fixed cost we can proceed to finding the equations for the variance using the sample sizes just determined.

4.2 Variance formulas using the sample sizes of minimum variance for fixed cost

A substitution of the sample sizes given in (16) and (17) into equation (8) gives as the variance of the proportion with double sampling,

$$\text{Var } P_j = \frac{\left(\sqrt{V_a c_1} + \sqrt{V_n c_2}\right)^2}{C_0} \tag{18}$$

The variance of simple random sampling is

$$\text{Var } P_j = \frac{s^2 \; c_1}{C_0}$$

where,

$$s^2 = p_j \left(1 - p_j\right), \tag{19}$$

and

$$p_j = \frac{a_j}{a}$$

4.3 Comparison of the two variances

From the two equations for the variance of the proportion it can be seen that double sampling would be more efficient than simple random sampling if

$$\frac{\left(\sqrt{V_a c_1} + \sqrt{V_n c_2}\right)^2}{C_0} < \frac{s^2 c_1}{C_0} \tag{20}$$

or

$$\sqrt{V_a c_1} + \sqrt{V_n c_2} < s \sqrt{c_1} \tag{21}$$

or

$$\frac{c_2}{c_1} < \left(\frac{s - \sqrt{V_a}}{V_n} \right)^2 \tag{22}$$

5 RESULTS AND CONCLUSIONS

5.1 Comparison of the methods

Estimates of the unit costs of sampling, based on an analysis of the 1961 season's sampling are:

$$c_1 = \$1.85 \text{ and } c_2 = \$0.30$$

therefore,

$$\frac{c_2}{c_1} = 0.162.$$

The results of inequality (22) are given in Table II for two port-months. For each age group in the two port-month strata the term on the right of (22) is larger than 0.162. The conclusion to be drawn from this result is that double sampling is more efficient than simple random sampling for the given unit costs.

5.2 Sample sizes for future sampling

The sample sizes that will be required within the port-month strata for a minimum variance with a fixed cost are found through equation (16) and (17); the results for a fixed cost of $1,000 per port-month stratum are tabulated in Table III. The sample sizes needed to estimate the relative contribution of each age group vary with age and port-month. Choosing a set of sample sizes to be used during each port-month among those calculated presents a problem. For example, a length sample of 955 and an age sample of 386 during July at Los Angeles will estimate the III age group with a minimum variance, with a fixed cost of $1,000. These same sample sizes, however, will not necessarily produce minimum variances for the other age groups. The chosen sample sizes would have to be used to find the expected variances of the estimates for the other age groups and a decision made as to acceptability of these expected variances. In the case of $n = 955$ and $a = 385$ for July sampling at Los Angeles, the expected variances of the other age groups were acceptable. The expected variances using $n = 955$ and $a = 385$ for July and 885 and 397 for August are in Table IV.

Of course, age composition, and hence variances of the estimates of age composition, will not remain constant from year to year. Thus, the estimates of the required sample sizes, based on the variances of the 1961 survey, are not magic numbers to which one should strictly adhere, but are guides for increasing the efficiency of sampling.

o

Table II

Computed Values of $\frac{\left(s - \sqrt{V_a}\right)^2}{V_n}$

For Two Months at Los Angeles

AGE GROUP	MONTH JULY	AUGUST
I	0.907	0.273
II	1.048	0.476
III	0.854	1.007
IV	2.164	2.735

The values in Table II are compared to $\frac{c_2}{c_1} = .162$ in inequality (22), to test the efficiency of double sampling over simple random sampling.

Table III

Estimated Sample Sizes for Minimum Variance With Fixed Port-Month Sampling Cost of \$1,000 and Unit Costs of c_1 = \$1.85 and c_2 = 0.30

Port: Los Angeles

MONTH	ESTIMATE	AGE GROUP			
		I	II	III	IV
JULY	a	390	396	385	431
	n	927	889	954	674
AUGUST	a	331	356	397	442
	n	1292	1136	885	609

Table IV

Expected Variances For Two Port-Months Using Sample Sizes Computed For Age Group III

Port: Los Angeles

		AGE GROUP			
MONTH	SAMPLE SIZES	I	II	III	IV
JULY	n = 955 a = 385	0.00008701	0.00041238	0.00043974	0.00008110
AUGUST	n = 885 a = 397	0.00006507	0.00017928	0.00039248	0.00023240

Experience Paper No. 21

CALIFORNIA'S TUNA RECORD GATHERING SYSTEM

By

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Abstract

Processing of catch statistics by the State of California is described with emphasis on tuna. Fish receipt usage and inventory methods as well as sale of licenses and registrations are discussed. Water origins, to locate the fisherman's catch, and albacore logs complete the basic source material processed by California. Information on processor records and reports is included along with details on tabulated reports for administrative and research work

METHODES EMPLOYEES EN CALIFORNIE POUR LE RASSEMBLEMENT DES STATISTIQUES THONIERES

Résumé

La communication décrit les méthodes employées dans l'Etat de Californie pour le dépouillement et l'exploitation des statistiques relatives aux pêches, plus particulièrement concernant les thons. Elle passe en revue le système des formules que doivent remplir les utilisateurs du poisson et celui des listes de contrôle, ainsi que le droit de licence et d'immatriculation. Les données de base sont complétées par des renseignements sur les zones de provenance des prises, et par les fiches remplies par les pêcheurs d'albacores. Le document traite également des états et rapports soumis par les transformateurs, et contient des précisions sur les données mises en tableaux aux fins de travaux administratifs et de recherche.

SISTEMA DE ACOPIO DE MATERIAL ESTADISTICO SOBRE EL ATUN EN CALIFORNIA

Extracto

Se describe el procedimiento elaborativo de las estadísticas de captura seguido por el Estado de California, especialmente en lo que se refiere al atún. Se exponen los métodos empleados para los resguardos o recibos del pescado, para los inventarios, las licencias de venta y los registros. Los orígenes de las aguas, para localizar la captura de cada pescador, y los libros registros de albacora, completan los antecedentes fundamentales del material manejado en California. Se incluyen también datos sobre la confección mecánica de fichas e informes, con detalles relativos a la tabulación para los trabajos administrativos y de investigación.

1 INTRODUCTION

To understand any fishery requires accurate catch records, which trace the fishery's development and denote areas of commercial exploitation.

We owe much of our knowledge of the eastern Pacific tunas to individuals who had the vision to enact useful legislation over 45 years ago. Early California marine fisheries research workers realized the importance of accurate records and helped secure legislation requiring dealers to report all commercial landings on forms provided by the State. Catch figures are essential for the biologist as well as for the administrator and industry; and California's statistical system is designed to gather and compile individual boat catch records.

In brief, the California Fish and Game Code (compendium of laws enacted by the State legislature) requires the Department to:

> "a) Gather and prepare data of the commercial fisheries related to the most important commercial fish, showing particularly the extent to which such fish abound.
>
> "b) Make such investigations of the biology of the various species of fish as will aid in the collection and preparation of the statistical information necessary to determine overfishing."

Beginning in 1917, catches were recorded and summarized by hand. We installed in 1931 the first electric IBM tabulating machines for fisheries work in the world. This equipment enabled us to record extensive detail vital for tuna research.

As we gained experience and received data requests in myriad forms, machine reports were modified. Larger machine capacity and more sophisticated techniques enabled us to improve reports. As a result, some reports became obsolete or unnecessary; these were eliminated. A brief description of our system, with emphasis on tuna is included in this article. A more extensive, though partially out dated, general description appears earlier in publication (California Department of Fish and Game, 1952).

2 FISH RECEIPTS

2.1 Use

Source documents (fish receipts) are issued in three different forms. Two may be used for tuna purchases.

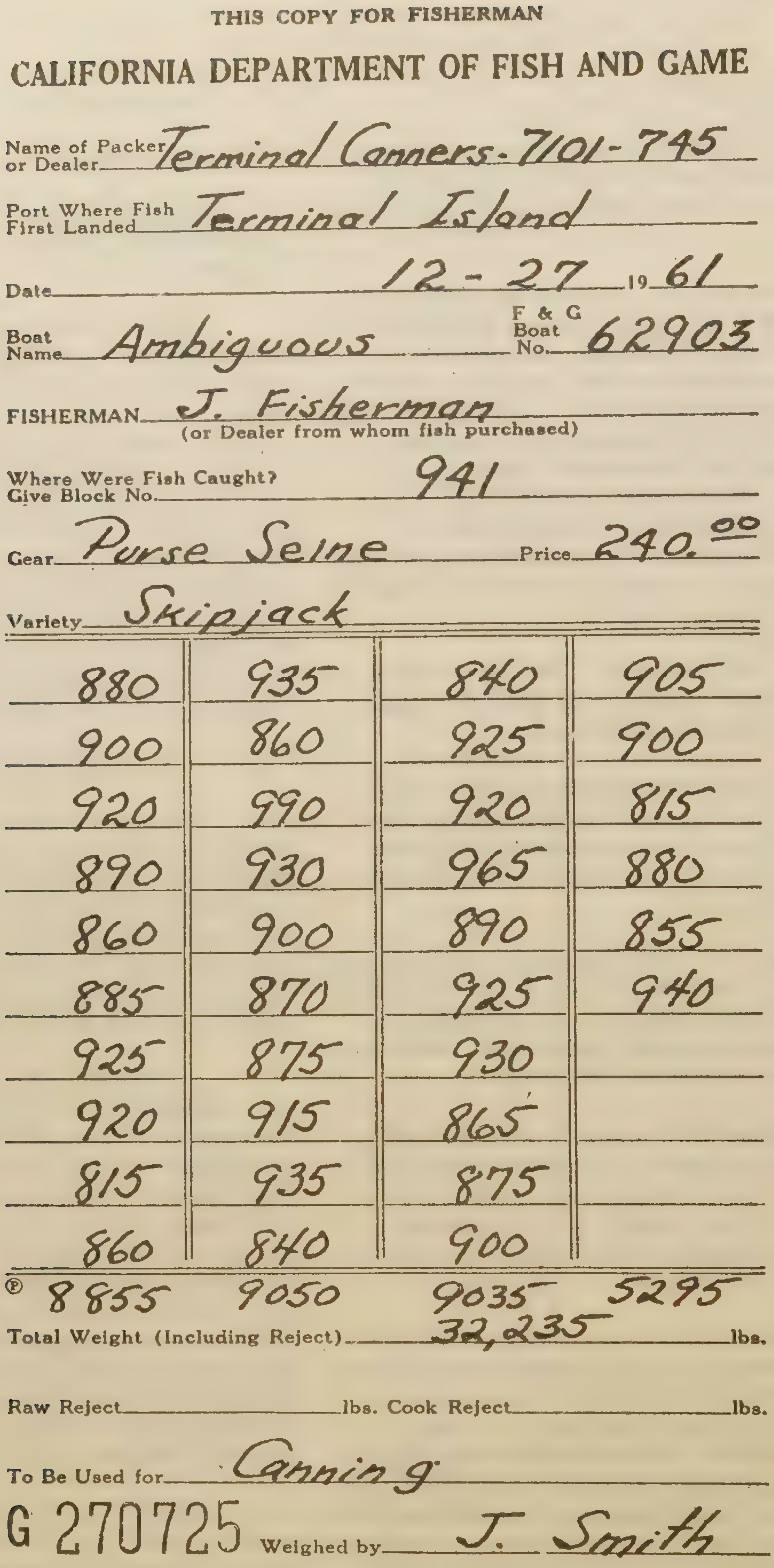
Processors, the primary recipients of tuna, use the receipt (Fig. 1) to record the quantity of each species received. The fisherman's name, boat name, and Fish and Game boat license number are supposed to be properly recorded, as in Fig. 1; however, if the purchaser fails to enter the Fish and Game boat number on the receipt, the other information enables us to find the proper one. We use this number in all subsequent work but not the fisherman's or boat's name. Shipments of tuna received for processing are noted on the same form. The country of origin and port of landing are recorded, and these imports are shown separately in our records.

2.2 Fish receipt inventory system

Wholesale dealers or processors who buy fish from fishermen complete a receipt in quadruplicate at the time of delivery: the original goes to the fisherman, the duplicate to the dealer and the triplicate to the Department. The fourth copy may be retained by the branch office or buyer for his record. In some instances, it is given to the union or fisherman's agent.

A complete fish receipt inventory system was established in 1950 to insure the return of receipts to the Department and also to maintain an adequate supply for peak seasons. A central fish-receipt-book supply is kept at Biostatistics, Terminal Island, and blocks of books are issued to our five field offices at strategic locations along the coast (Eureka, San Francisco, Monterey, Terminal Island, and San Diego). Each field office maintains an inventory of every book and ticket to assure that each dealer submits all issued to him. When the completed fish receipt is received in the local office, the date is recorded on an inventory card.

Since the law requires the dealer to transmit tickets on the 1st and 16th of each month, these inventory cards aid our law enforcement activities.



THIS COPY FOR FISHERMAN

CALIFORNIA DEPARTMENT OF FISH AND GAME

Name of Packer or Dealer Terminal Canners - 7101 - 745

Port Where Fish First Landed Terminal Island

Date 12 - 27 19 61

Boat Name Ambiguous F & G Boat No. 62903

FISHERMAN J. Fisherman
(or Dealer from whom fish purchased)

Where Were Fish Caught? Give Block No. 941

Gear Purse Seine Price 240.00

Variety Skipjack

880	935	840	905
900	860	925	900
920	990	920	815
890	930	965	880
860	900	890	855
885	870	925	940
925	875	930	
920	915	865	
815	935	875	
860	840	900	
℗ 8855	9050	9035	5295

Total Weight (Including Reject) 32,235 lbs.

Raw Reject lbs. Cook Reject lbs.

To Be Used for Canning

G 270725 Weighed by J. Smith

Fig. 1 Cannery receipt

3 LICENSES

3.1 Commercial fishing and boat registration licenses

Each person who fishes or assists in commercial fishing operations or who brings fish ashore to sell must purchase a commercial fishing license. The fee in 1962 was $15.00. Vessels used in commercial fishing operations must be registered. In 1962, the fee for registering a boat was $10.00. Licenses are issued annually and are valid for the period April 1 through March 31 and their renewal facilitates our being able to maintain accurate boat records. Commercial license sales comprise an important part of the Department's revenue.

In recent years, licenses have been simplified, and unnecessary duplication of writing was eliminated by combining the application with the license and by using multiple copies. Licenses are sold by the same field offices that issue fish receipt books. Selected agents who are familiar with commercial fishing operations also sell commercial licenses and boat registrations; they receive a five percent commission on their license sales.

3.2 Boat registration plates

The first time a fishing vessel registers, it is issued Fish and Game number plates and the number stays with the boat regardless of changes in ownership. All subsequent landings are credited to the number on the plates. The first plates issued are free, but if lost or destroyed replacements cost $2.00 per plate.

One of our previous publications (California Department Fish and Game, 1952) reported that when vessels were lost or dismantled, their identifying Fish and Game number was reissued after at least five years had elapsed. To prevent any chance of confusion in catch records, Fish and Game numbers are no longer reissued.

4 CATCH ORIGINS

4.1 California water origins

Precise water origin or location of the fisherman's catch is one of the most valuable pieces of information but often is the most difficult to obtain on the fish receipt. California early established a block area system for local waters, each block being 10 minutes of latitude and 10 minutes of longitude on a side. When most fishing trips were local and of short duration, this origin system was satisfactory. Its value became limited for tuna research when improved vessels fished in more distant waters, though for local fisheries it is still satisfactory.

4.2 Water origins south of California

A telescopic system was established in May 1938 to describe water areas between the United States-Mexico border and lat. 02° south (Fig. 2).

With this system, five numbers describe successively larger areas between the California-Mexican Border and lat. 02° south. Thus, if a fisherman's catch was made over a broad area or he could not remember a specific locality for a given holdfull of tuna, there is a number which will encompass his entire trip.

The five numbers (zone codes) and the areas they delimit are:

Zone code	Northern limit	Southern limit
910	32° 30'N	27° 23'N
920	32° 30'N	22° 00'N
930	32° 30'N	16° 12'N
940	32° 30'N	07° 30'N
950	32° 30'N	02° 00'S

We could use only nine numbers within each "zone" we established so we used four to describe coastal areas and five remained to designate offshore banks or islands (Fig. 2).

Prior to 1958, we had no specific numbers assigned south of 02° S. When fleet activities expanded into Peru and Chile in 1958, we utilized numbers in the 960 to 969 series to cover them. As a result, 960 was used for the general area below 02° S. The remaining numbers indicated small to large areas both inshore and off (Fig. 2).

This deviated from our basic telescopic system but within the former series little flexibility remained.

4.3 Origin number expansion

In 1953, we increased our punch-card origin field to four columns and our former numbering system, limited to three columns, was modified and incorporated into the larger field, permitting greater expansion.

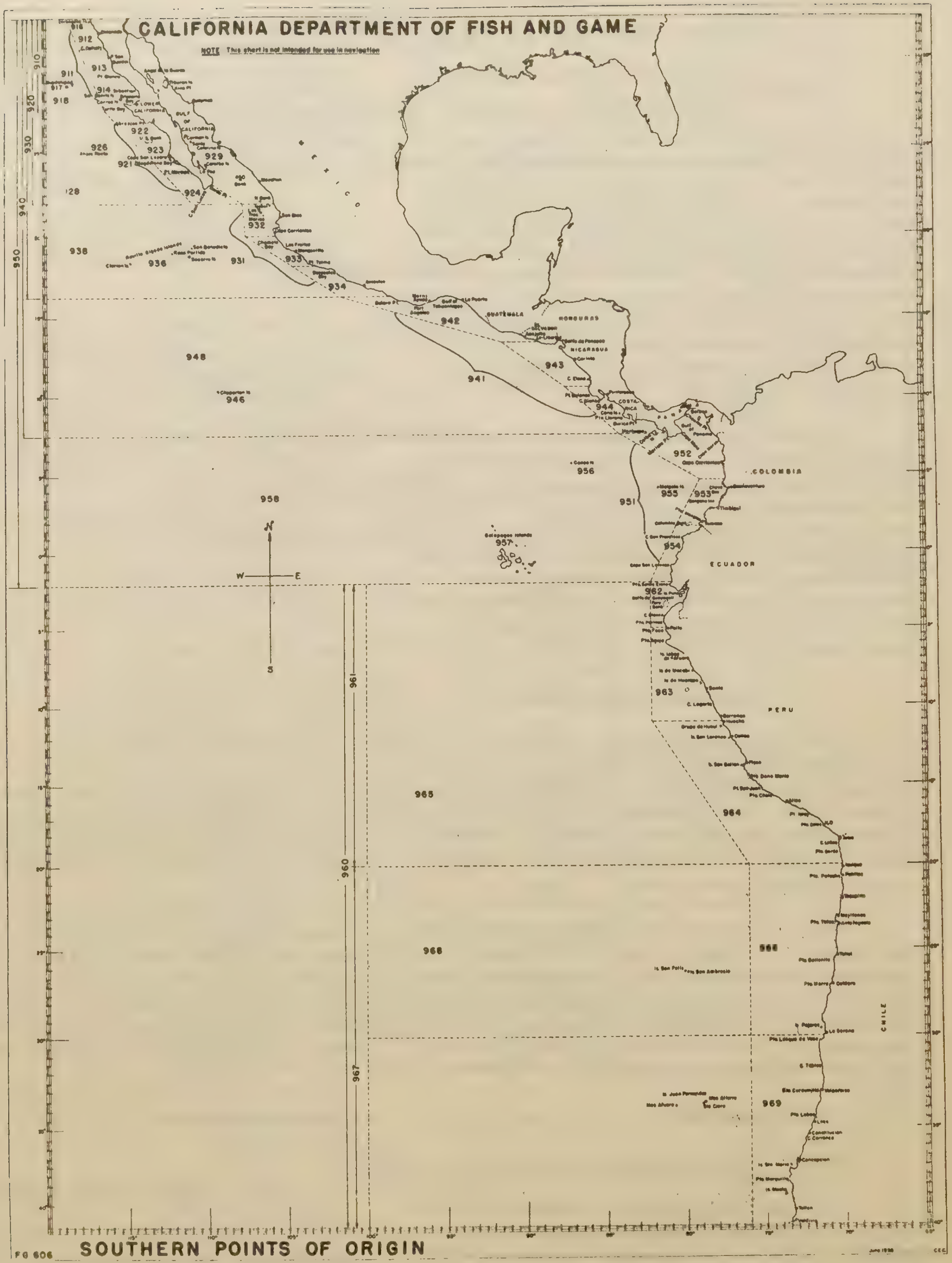

CALIFORNIA DEPARTMENT OF FISH AND GAME
NOTE This chart is not intended for use in navigation
912
911
913
914
918
910
920
930
940
950
922
923
926
921
924
929
931
932
933
934
936
938
941
942
943
944
946
948
951
952
953
954
955
956
957
958
960
961
962
963
964
965
966
967
968
969
MEXICO
GUATEMALA
HONDURAS
NICARAGUA
COSTA RICA
COLOMBIA
ECUADOR
PERU
CHILE
N
W
E
S
SOUTHERN POINTS OF ORIGIN
FG 606

Fig. 2 Water areas between U.S.-Mexican border and lat. 02° South with zone codes off coastal areas and offshore banks or islands

We assigned, as needed, four-digit numbers to cover shipments from foreign countries and boat activities in new areas. These figures incorporated the older system so the two remained compatible.

Block areas in our present southern-points-of-origin chart have an advantage in being fairly big. This enables the fisherman to describe his catch area with a specific number. A disadvantage is that in data reduction and analysis, we must use a block which at best is quite large. Tuna catch origins cannot be assigned to the widely-used one-degree squares on a fish receipt since the catch may originate from many such squares. An auxiliary log book system must be utilized to gain these data.

5 ALBACORE LOGS

Albacore logs (Fig. 3) are issued to selected boats by the albacore research staff which also edits those completed and returned by fishermen. Additional information is obtained by interviewing fishermen, by sampling their catch and by using fish receipt records.

Vessel name, Fish and Game number, departure and return date plus the first four columns on the right side of the log are completed by the fishermen. A statistical clerk enters the trip number and the vessel length to the left of the vessel name, The research worker adds latitude and longitude and the total weight of the catch shown on the fish receipt. Number of days absence and days fishing are placed on the log for use in effort studies.

Prior to punching the data into an IBM card, the average weight of the albacore is ascertained in order to assure that the log is correct and agrees with field information. The cards are then processed through a computer and the daily catch weight entered into each card. Numerous reports are then tabulated to assist the research worker in his analysis.

From these analyses and from corollary data, California issues annual newsletters to fishermen giving details on the previous year's fishing and general predictions for the forthcoming season.

6 FISH DEALERS' AND PROCESSORS' LICENSES

6.1 License types

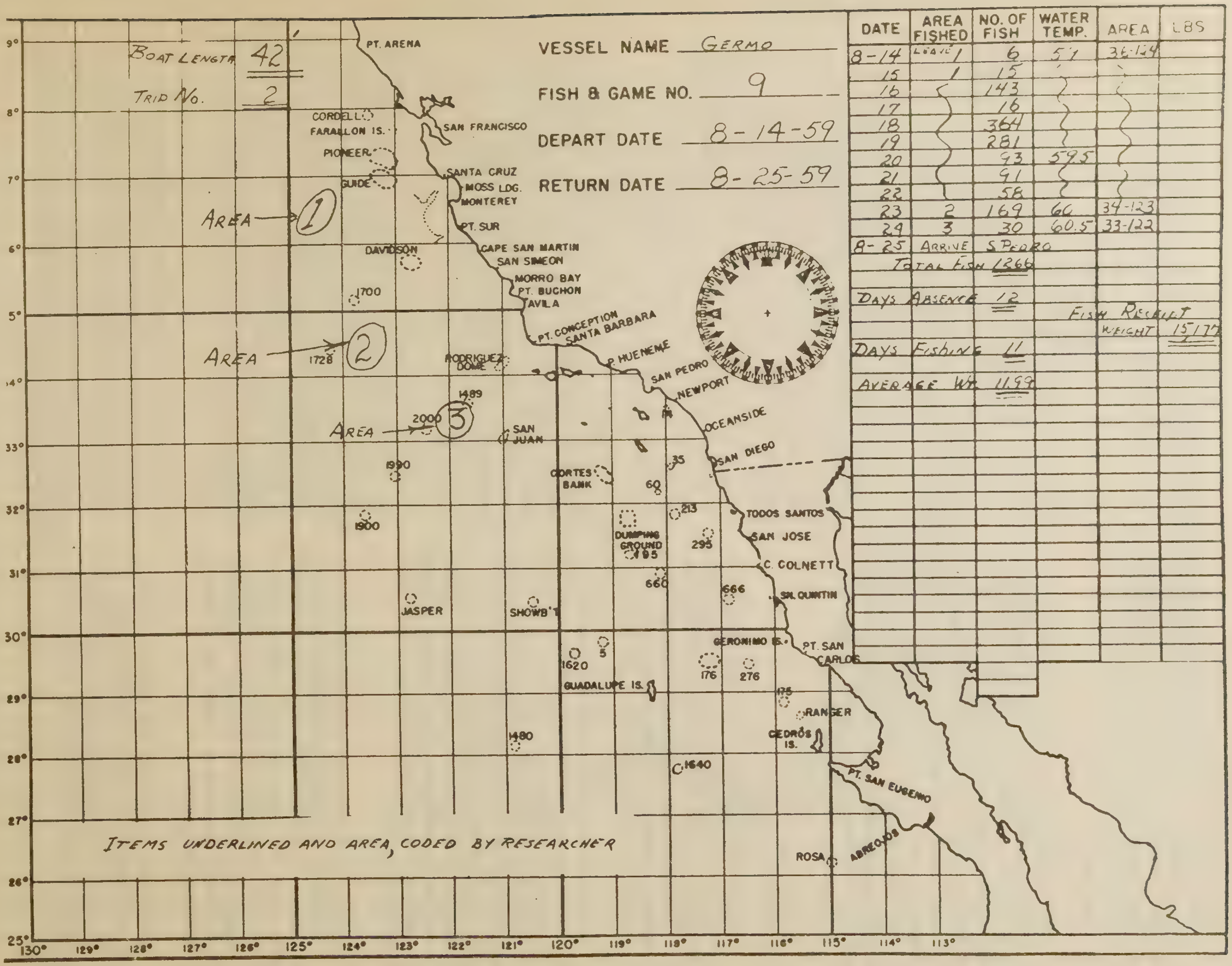
In 1954, wholesale fish dealer license fees were increased from $5.00 to $25.00 and fish canner's and processor's licenses were increased from $5.00 to $75.00. The $25.00 license entitles the possessor to purchase fish from fishermen and to preserve fish by the common methods of salting, cold packing, smoking and drying. In order to can fish, the significant item for the tunas, or make fish meal, a $75.00 license is required. These fee increases were the first since inception of the "Wholesale Dealers License Act" in 1911. Fish brokers' licenses were established in 1961. This $25.00 license permits an individual or company to act as a wholesaler as long as he does not purchase fish from fishermen. Fish receipt records required of the wholesaler or fish dealer are not required of the broker.

7 PROCESSORS' REPORTS

While the fish receipt system, discussed in section 2 yields a complete record of every pound of fish landed commercially in California, it does not tell the quantities of processed fish produced. Although this information is of secondary importance to the fishery biologist it is important to both government and the fishing industry.

Each processor is required by law to submit a monthly report of the actual amount of fish received at each plant, the amount packed and the number and size of containers packed therefrom; plus the kind and quantity of by-products produced during the preceding month. Each processor must also submit an annual statement telling the amount and kind of fishery products canned, preserved or manufactured the preceding year.

No single report could conveniently cover the diverse products produced; hence, forms have been prepared and modified from time to time to secure this information in a concise and convenient manner. A typical report with entries that could have been made by any tuna canner is illustrated in Fig. 4.


PT. ARENA
SAN FRANCISCO
CORDELL
FARALLON IS.
PIONEER
GUIDE
SANTA CRUZ
MOSS LDG.
MONTEREY
PT. SUR
CAPE SAN MARTIN
SAN SIMEON
MORRO BAY
PT. BUCHON
AVILA
PT. CONCEPTION
SANTA BARBARA
P. HUENEME
SAN PEDRO
NEWPORT
OCEANSIDE
SAN DIEGO
TODOS SANTOS
SAN JOSE
C. COLNETT
SN. QUINTIN
GERONIMO IS.
PT. SAN CARLOS
RANGER
CEDROS IS.
PT. SAN EUGENIO
ABREOJOS
ROSA
DAVIDSON
1700
1728
RODRIGUEZ DOME
1489
2000
SAN JUAN
1990
1900
CORTES BANK
35
60
213
295
DUMPING GROUND
195
660
666
JASPER
SHOWB'T
1620
5
GUADALUPE IS.
176
276
175
1480
1640
AREA ①
AREA ②
AREA ③
9°
8°
7°
6°
5°
4°
33°
32°
31°
30°
29°
28°
27°
26°
25°
130°
129°
128°
127°
126°
125°
124°
123°
122°
121°
120°
119°
118°
117°
116°
115°
114°
113°

BOAT LENGTH 42

TRIP No. 2

VESSEL NAME GERMO

FISH & GAME NO. 9

DEPART DATE 8-14-59

RETURN DATE 8-25-59

DATE	AREA FISHED	NO. OF FISH	WATER TEMP.	AREA	LBS
8-14	LEAVE 1	6	57	36-124	
15	1	15			
16		143			
17		16			
18		364			
19		281			
20		93	59.5		
21		91			
22		58			
23	2	169	66	34-123	
24	3	30	60.5	33-122	
8-25	ARRIVE	S PEDRO			

TOTAL FISH 1266

DAYS ABSENCE 12

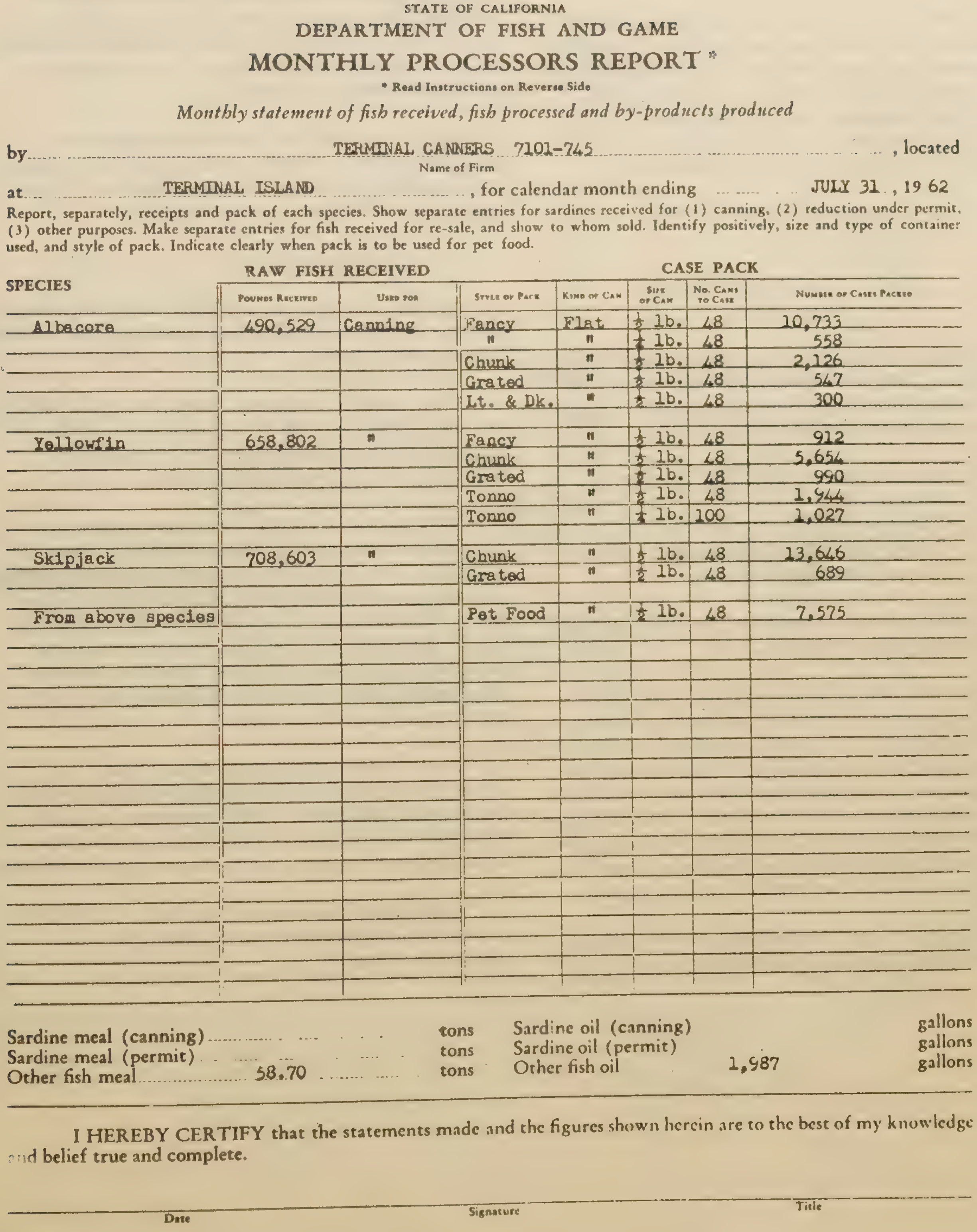
FISH RECEIPT WEIGHT 15177

DAYS FISHING 11

AVERAGE WT. 11.99

ITEMS UNDERLINED AND AREA, CODED BY RESEARCHER

Fig. 3 Albacore Log. (Area designation assigned latitude and longitude by researcher)



STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME
MONTHLY PROCESSORS REPORT *
* Read Instructions on Reverse Side

Monthly statement of fish received, fish processed and by-products produced

by TERMINAL CANNERS 7101-745, located
Name of Firm

at TERMINAL ISLAND, for calendar month ending JULY 31, 19 62

Report, separately, receipts and pack of each species. Show separate entries for sardines received for (1) canning, (2) reduction under permit, (3) other purposes. Make separate entries for fish received for re-sale, and show to whom sold. Identify positively, size and type of container used, and style of pack. Indicate clearly when pack is to be used for pet food.

SPECIES	RAW FISH RECEIVED		CASE PACK				
	Pounds Received	Used for	Style of Pack	Kind of Can	Size of Can	No. Cans to Case	Number of Cases Packed
Albacore	490,529	Canning	Fancy	Flat	½ lb.	48	10,733
			"	"	¼ lb.	48	558
			Chunk	"	½ lb.	48	2,126
			Grated	"	½ lb.	48	547
			Lt. & Dk.	"	½ lb.	48	300
Yellowfin	658,802	"	Fancy	"	½ lb.	48	912
			Chunk	"	½ lb.	48	5,654
			Grated	"	½ lb.	48	990
			Tonno	"	½ lb.	48	1,944
			Tonno	"	¼ lb.	100	1,027
Skipjack	708,603	"	Chunk	"	½ lb.	48	13,646
			Grated	"	½ lb.	48	689
From above species			Pet Food	"	½ lb.	48	7,575

Sardine meal (canning) tons
Sardine meal (permit) tons
Other fish meal 58.70 tons

Sardine oil (canning) gallons
Sardine oil (permit) gallons
Other fish oil 1,987 gallons

I HEREBY CERTIFY that the statements made and the figures shown herein are to the best of my knowledge and belief true and complete.

Date Signature Title

Fig. 4 Sample of monthly processing report

8 TABULATED REPORTS

Tabulated reports derived from source documents are numerous and varied. Original documents can be broken down into four categories: commercial landings, biological data, processors records, and marine sport-catch logs. The reports of primary interest in tuna research fit into the first two categories.

8.1 Commercial fishery landing reports

8.1.1 Monthly and annual tabulation

Fish receipts form the backbone of these tabulations. We emphasize both accuracy and speed when compiling monthly and annual figures. Our four regular monthly reports are:

1. Daily Boat Listing (Fig. 5, report simplified)
2. Place of First Landing (Fig. 5)
3. Geographic Origin (Fig. 6)
4. Cummulative (not shown)

All of these are designed to yield current preliminary landing figures.

The daily-boat-catch report (Fig. 5) is a simplified version of the actual monthly listing report. Regular boat listings contain all the information written on the fish receipt except the boat name and the fisherman's name. In addition to the information on the receipt, codes are provided for type of ticket (fresh fish, cannery, etc.), condition of fish (whole or some state other than round), and whether or not the fish is taxable.

Our place-of-first-landing report (Fig. 5, top) gives us current port data.

The geographic-origin report (Fig. 6) records landings and shipments in the separate areas of the State. Catches from California waters are separated from those made north and south of the State boundaries. For shipments, we show country of origin.

The cummulative report is designed to give a thumbnail sketch of all previous landings. It lists separate totals for each species. Consolidated reports are issued annually.

8.2 Special reports

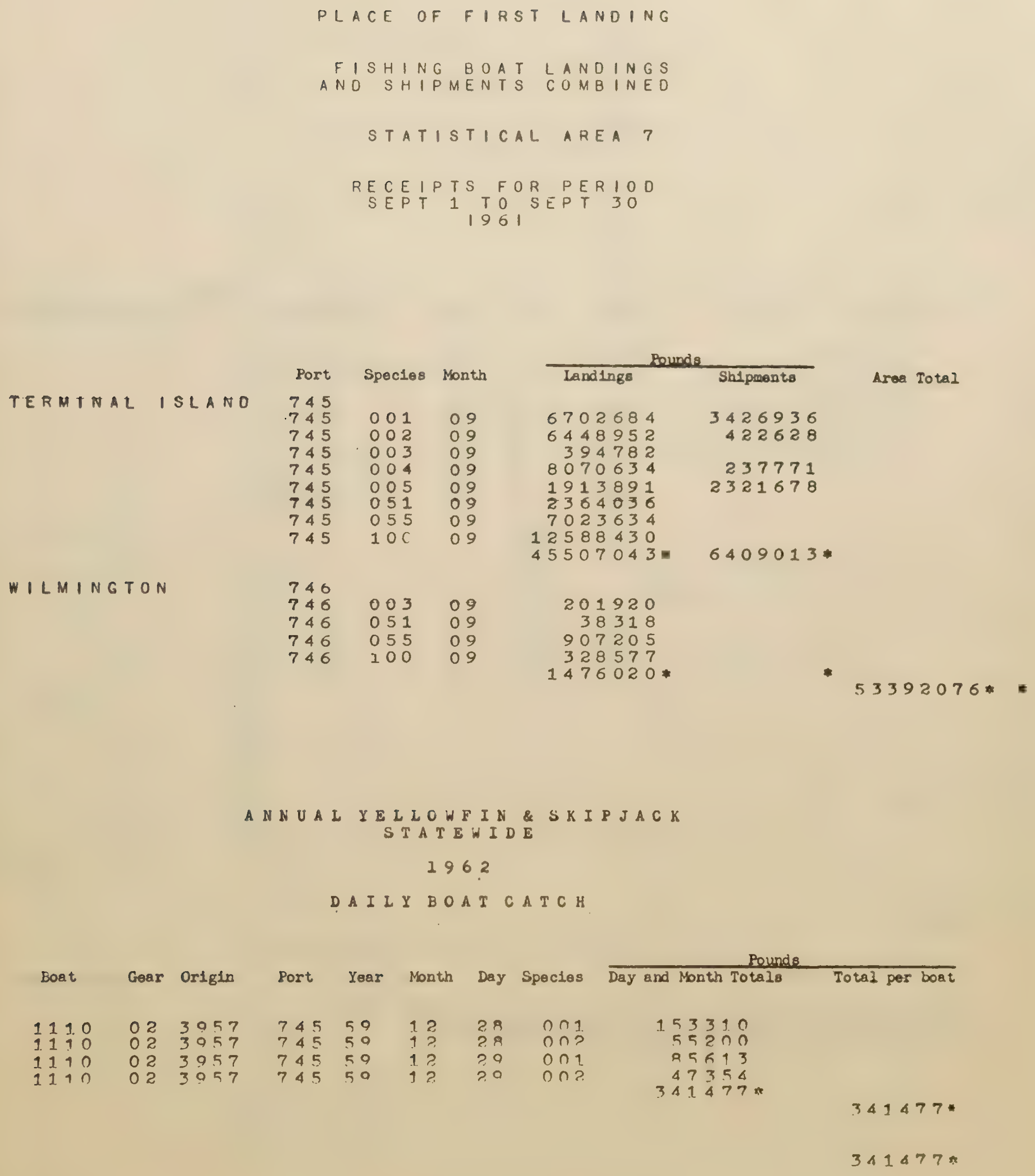
Special reports, apart from catch reports, and varied types of biological data may be reduced to analyzable form.

Two reports compiled from biological data are illustrated in Fig. 7. These show some of the potentials of automation where rapid and important strides are being made.

The top report (Fig. 7) records complete sampling information. Under "method sampled" a code is used by the biologist to describe various random methods and sampling stations in a cannery. "General area of catch" combines a number of small block areas into larger ones that have been preselected by the research worker. Information contained in this report may be compiled in various other ways.

In the length-frequency report (Fig. 7, bottom), 50 yellowfin tuna have been arrayed by centimeter intervals. The frequency of observation at each length is recorded and machine computations express percentages for the sample.

Biological reports are limited only by the needs and imaginations of the biologists and report designers.



```
                              PLACE OF FIRST LANDING

                               FISHING BOAT LANDINGS
                              AND SHIPMENTS COMBINED

                                STATISTICAL AREA 7

                                RECEIPTS FOR PERIOD
                                SEPT 1 TO SEPT 30
                                      1961



                                                       Pounds
                      Port  Species  Month     Landings      Shipments      Area Total
TERMINAL ISLAND       745
                      745    001      09       6702684       3426936
                      745    002      09       6448952        422628
                      745    003      09        394782
                      745    004      09       8070634        237771
                      745    005      09       1913891       2321678
                      745    051      09       2364036
                      745    055      09       7023634
                      745    10C      09      12588430
                                              45507043*      6409013*
WILMINGTON            746
                      746    003      09        201920
                      746    051      09         38318
                      746    055      09        907205
                      746    100      09        328577
                                               1476020*              *
                                                                         53392076*  *
```

```
                         ANNUAL YELLOWFIN & SKIPJACK
                                  STATEWIDE

                                    1962

                              DAILY BOAT CATCH

                                                                       Pounds
 Boat    Gear Origin   Port  Year  Month  Day  Species  Day and Month Totals   Total per boat

 1110    02   3957     745   59    12     28   001           153310
 1110    02   3957     745   59    12     28   002            55200
 1110    02   3957     745   59    12     29   001            85613
 1110    02   3957     745   59    12     29   002            47354
                                                             341477*
                                                                                341477*

                                                                                341477*
```

Fig. 5 Place of first landing report (top); Simplified boat listing report (bottom)

GEOGRAPHIC ORIGIN

FISHING BOAT LANDINGS AND
OR SHIPMENTS

STATEWIDE

RECEIPTS FOR PERIOD
SEPT 1961

FISHING BOAT LANDINGS CALIFORNIA WATERS	Species	Area	Month	Pounds Month & Area	 Geographic Origin 1/
ALBACORE	005	4	09	1735035	
	005	5	09	1095552	
	005	6	09	279976	
	005	7	09	1917895	
	005	8	08	425	
	005	8	09	1069416	
				1069841*	
					6098299*
SO OF STATE BOUNDARY					
	005	7	09	30944	
	005	8	09	566778	
					597722*
SHIPMENTS					
MEXICO					
	005	7	09 1	616	
					616*
JAPAN					
	005	7	09 1	2321062	
					2321062*

1/ On regular reports totals are given for each species and total for all species combined for each major geographic origin.

Fig. 6 Sample of geographic-origin report

REPORT I

YELLOWFIN LISTING REPORT

1962

Fish & Game No.	Sample No.	Gear	Method Sample	Period of Catch Year	Month	Quarter	General Area Caught	Block No.	Port Sampled	C.M. Group	No. of Fish	No. Fish per Sample
1056	30	02	6	55	03	2	06	933	745	47	1	
1056	30	02	6	55	03	2	06	933	745	50	2	
1056	30	02	6	55	03	2	06	933	745	51	1	
												4

REPORT II.1 - YELLOWFIN MONTHLY AREA STUDY
BAIT BOAT CATCHES

Species	Gear	Area	Year	Month	c.m. Group	No. of Fish	Percent	Total No. of Fish per Area Month	Year
001	02	3	57	09	54	3	06000		
					55	3	06000		
					56	5	10000		
					57	5	10000		
					58	9	18000		
					59	8	16000		
					60	6	12000		
					61	6	12000		
					62	4	08000		
					63	1	02000		
							100000*	50*	
									50

Fig. 7 Sampling data report (top); Length frequency array (bottom)

Experience Paper No. 22

STUDIES OF THE ERYTHROCYTE ANTIGENS OF ALBACORE, BIGEYE, SKIPJACK, AND YELLOWFIN TUNAS AND THEIR USE IN SUBPOPULATION IDENTIFICATION

By

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Abstract

Initial studies of the serology of albacore, bigeye, skipjack, and yellowfin tunas are discussed. The discovery in bigeye of a blood group system containing two blood factors, A and B, which form four phenotypes A, B, AB, and O is noted, and gene frequency estimates are calculated consonant with the hypothesis that the system is determined by the inheritance pattern of three allelic genes. The importance of being able to study such systems for subpopulation analysis is pointed out.

The relationships of several other blood factors within the four tunas studied were discussed and the K set of blood factors in the B system of skipjack was analyzed. This system provided evidence for reproductive isolation between at least two and probably three subpopulations in the area of four island groups: Hawaii, the Marquesas, the Tuamotu, and the Society Islands.

ETUDE DES ANTIGENES ERYTHROCYTES DU THON GERMON, DU THON OBESE, DE LA BONITE A VENTRE RAYE ET DU THON A NAGEOIRES JAUNES

Résumé

L'article présente des recherches initiales portant sur la sérologie du thon germon, du thon obèse, de la bonite à ventre rayé et du thon à nageoires jaunes. Il signale la découverte chez le thon obèse d'un système de groupes sanguins contenant deux facteurs sanguins, A et B, qui forment quatre phénotypes A, B, AB et O, et les estimations de fréquence des gènes se montrent en accord avec l'hypothèse selon laquelle le système est déterminé par la distribution héréditaire des trois gènes alléliques. Les auteurs soulignent l'importance que l'étude de tels systèmes présenterait dans l'analyse des sous-populations.

Ils commentent les relations qui peuvent exister entre plusieurs autres facteurs sanguins dans les quatre espèces de thon étudiées et ils analysent l'ensemble K des facteurs sanguins dans le système B de la bonite à ventre rayé. Cette méthode apporte la preuve de l'existence d'une reproduction séparée de deux, au moins, et probablement trois sous-populations dans la zone des archipels des Hawaï, des Marquises, des Tuamotou et des Iles de la Société.

ESTUDIOS DEL ERYTHROCYTE ANTIGENS DE ALBACORA, PATUDO, BARRILETE Y ATUN DE ALETA AMARILLA Y SU EMPLEO EN LA IDENTIFICACION DE SUBPOBLACIONES

Extracto

Se reseñan los estudios iniciales de la serología de albacora, patudo, barrilete y atún de aleta amarilla. Se menciona el descubrimiento en el patudo de un sistema de grupo de sangre que contiene dos factores, A y B, que forman cuatro fenotipos: A, B, AB, y O y se hacen estimaciones de la frecuencia de genes de acuerdo con la hipótesis de que el sistema lo determina la modalidad de la herencia de los tres genes alélicos. Se pone de relieve la importancia de poder estudiar tales sistemas para el análisis de subpoblaciones.

Se reseñan las relaciones de varios otros factores de la sangre dentro de los cuatro atunes estudiados y se analiza el grupo K de factores sanguíneos en el sistema B del barrilete. Este sistema facilitó las pruebas del aislamiento reproductivo entre por lo menos dos, y probablemente tres, subpoblaciones en aguas de cuatro grupos de islas: Hawaii, Marquesas, Tuamotu y Sociedad.

1 INTRODUCTION

The purpose of this report is to give an account of our initial studies of the antigens found on the erythrocytes of four Pacific tunas: albacore, bigeye, skipjack, and yellowfin. This study was undertaken to establish serological techniques whereby reproductively isolated stocks of tuna could be recognized by identifying genetically controlled antigens on the surface of the red blood cell envelope. Three blood group systems called B, C, and A-B-O are described, and several additional blood factors not yet identified with a particular blood group system are discussed.

The studies of numerous authors have discussed or shown the utility of this approach to the problem of distinguishing reproductively isolated populations within a single species (Cushing, 1952; Cushing and Sprague, 1952, 1953; Ridgway, 1957; Sindermann and Mairs, 1959; Suzuki, 1961; Suzuki et al., 1958, 1959, 1960; Ridgway and Klontz, 1960; Sprague and Vrooman, 1962; Marr and Sprague, in press).

2 MATERIALS AND METHODS

The results reported in this paper were obtained from blood samples drawn from four major species of Pacific tuna: albacore, bigeye, skipjack, and yellowfin.

Samples were collected via cardiac puncture and held in a modified Alsever's anti-coagulant containing 16 g sodium citrate, 41 g dextrose, and 14.5 g sodium chloride in 2 litres of H_2O. Stored in a refrigerator at approximately 7° C, the samples showed very little hemolysis over periods of 2 weeks to 2 months, depending on the species.

The reagents used in these studies were saline extracts of legume seeds and normal and immune animal sera. All reagents were kept in a freezer at -20° C in their undiluted state. Prior to testing they were thawed and diluted to proper strength.

The seed extracts were prepared by soaking 1 g of ground seeds in 5 ml of modified Alsever's at room temperature overnight. The solution was then centrifuged and the supernatant poured off. The supernatant was further diluted 1:6 for testing.

Absorbed and unabsorbed cattle and goat normal sera were prepared in a single standard dilution of 1:8. When questionable results occurred, absorptions were used as the final criteria of classification.

The immune sera were obtained from rabbits specifically immunized against bigeye, skipjack, or yellowfin tuna. These sera were also used as absorbed or unabsorbed reagents, and were diluted appropriately before testing, usually 1:16 to 1:64.

Absorptions of the normal and immune sera were performed using standardized techniques. In each instance 2 volumes of diluted sera were first absorbed by a single volume of tightly packed erythrocytes at room temperature for 10 minutes and then by a second volume of erythrocytes at 7° C for 20 minutes.

Titre for the absorbed sera ranged from 1:8 for the goat normal sera to 1:96 for rabbit immune serum.

3 BLOOD-TYPING TECHNIQUE

The procedures used to study each sample of tuna blood were as follows: .05 ml of reagent followed by .025 ml of a freshly washed 10-percent erythrocyte suspension were drawn into a 1.3-1.5 x 75 mm tube by capillary action. The total fluid involved occupied approximately three-quarters of the volume of the capillary tube. The tube was inverted and imbedded in soft clay contained in a slot on the face of a plastic block. The clay sealed the tube and held it in a near vertical position. This position allowed the cells to fall slowly through the reagent and maximum reaction to take place.

Agglutination readings were made by inverting the blocks and were recorded after 1 to 1-1/2 hours.

A scoring system employing the designations negative (.), trace (tr), and one (1) through four (4) was used. The weakest agglutination which could be observed macroscopically was designated a trace and the strongest clumping was designated a four. In the tables of this report only the summary designations "positive (+++)" or "negative (.)" are recorded.

4 NOMENCLATURE

In order to conform generally to conventional notation, serologically related sets of reactions detected by various reagents are designated as "systems" of blood groups, remembering that the present usage of this term is a special one, since the necessary genetic information, obtained from inheritance data, relating the reactions to allelic sets of genes is not available. It is assumed, however, that the erythrocyte antigens of tuna are the products of genes, as in other species. Evidence that this assumption is correct is presented below for the A-B-O system of bigeye.

5 SEROLOGICAL FINDINGS

5.1 The bigeye tuna

Two blood group systems and several additional blood factors have been demonstrated for the bigeye tuna.

5.1.1 The C system

Bovine normal sera have been shown to contain natural heteroagglutinins which react with many but not all tuna erythrocytes (Cushing, 1956). The blood factor recognized by such sera, which we have designated C_3, was the first factor of the C system to be recognized.

Two other blood factors which form regular serological subtyping relationships with C_3 are now recognized. These blood factors C_1 and C_2 were revealed by absorptions of rabbit anti-bigeye immune sera with selected bigeye red blood cells (RBC).

Table I shows the results of testing 335 bigeye blood samples with anti-C_1, anti-C_2, and anti-C_3 reagents. The pattern of phenotypes formed by these reactions constitutes a typical regular linear subtyping relationship.

Table I

Bigeye tuna from Hawaiian waters classified according to the four phenotypes of the C system. This table demonstrates the linear subtyping relationship of the reagents anti-C_1, anti-C_2, and anti-C_3

Phenotype	Reagent			Individuals tested
	Anti-C_1	Anti-C_2	Anti-C_3	
C_1	+++	+++	+++	184
C_2	.	+++	+++	34
C_3	.	.	+++	60
" "	.	.	.	57
				335

5.1.2 The A-B-O system

Anti-A reagent was obtained by the absorption of rabbit anti-yellowfin immune serum R329 by selected bigeye bloods. Anti-B reagent was obtained by the absorption of bovine normal serum C347 by selected bigeye bloods. We propose that the four phenotypic patterns detected by these reagents constitute a blood group system which is in form analogous to the human A-B-O system.

Both R329 and C347 contain various anti-C fractions. In each case it was necessary to remove these fractions before proceeding to an analysis of the anti-A and anti-B fractions of the serum; the relevant absorptions are shown in Tables II and III.

Anti-A reagents were prepared by absorptions similar to those shown in Table II. Bloods similar to 732 and 758 remove all C fractions from the serum R329 but fail to remove the anti-A components of the serum. Bloods of type O, C-negative (not shown) do not react in absorptions of either anti-C or anti-A fractions, while 630 and 749 and similar bloods completely exhaust the antibodies anti-C and anti-A from this serum.

Anti-B reagents were prepared from bovine normal serum C347 by selected bigeye bloods used in absorption experiments as shown in Table III.

Bloods similar to 704 and 694 remove all anti-C fractions but do not remove anti-B from the serum. Bloods similar to 695 do not remove

Table II

Absorption of rabbit anti-yellowfin serum R329 by selected bigeye bloods to obtain the anti-A reagent. The absorbing and test cells are individually classified according to their C system and A-B-O system phenotypes to illustrate the types of cross reactions involved.

Tested by bigeye RBC number	Rabbit anti-yellowfin serum R329 absorbed by bigeye RBC number					C and A-B-O phenotypes of test RBC	
	732	758	749	630	Unabs.	C	A-B-O
724	+++	+++	.	.	+++	"_"	A
726	.	.	.	.	+++	C_3	B
749	+++	+++	.	.	+++	C_1	AB
760	.	.	.	.	+++	C_1	O
615	+++	+++	.	.	+++	"_"	A
630	+++	+++	.	.	+++	C_1	A
C	C_1	C_1	C_1	C_1		C and A-B-O phenotypes of absorbing RBC	
A-B-O	B	O	AB	A			

either anti-C or anti-B fractions. Bloods similar to 702 will remove anti-B fractions but not the anti-C_2 fractions. Bloods similar to 653 remove all demonstrable antibody fractions from this serum.

Table IV shows the results of cross absorption experiments with the anti-A and anti-B reagents with various A, B, AB, and O bloods. The results of these absorptions are those expected by our assumption that these anti-A and anti-B reagents regularly classify the four A-B-O phenotypes.

In 1924 Felix Bernstein proposed a theory of the heredity of the A-B-O blood groups of man which he derived from the consequences of the Hardy-Weinberg law (Wiener and Wexler, 1958).

Simplified, Bernstein's formula states that $\sqrt{\bar{O}+\bar{A}} + \sqrt{\bar{O}+\bar{B}} - \sqrt{\bar{O}} = 1$ where $\bar{O}$ is the proportion of group O individuals, $\bar{A}$ the proportion of group A individuals, and $\bar{B}$ the proportion of group B individuals observed. This relationship holds for situations in which random mating exists and tests the theory that the four phenotypes in the population--A, B, AB, and O--are the products of the segregation of three allelic genes.

We have shown in Table V data on 427 bigeye tuna collected near Hawaii. The data in Table V are presented according to the expectations of Bernstein's formula. The observed value of 0.992 for Hawaiian bigeye tuna is not significantly different from the expected value 1.000.

We conclude from this observation that the observed data conform to those expected on a hypothesis of three allelic genes segregating to produce four phenotypes in the proportions shown, or, in other words, a blood group system like that of the A-B-O groups of man. Thus it may be said that the bigeye sampled were obtained from a single subpopulation.

Table III
Absorption of bovine normal serum C347 by selected bigeye bloods to obtain the anti-B reagent. The individual absorbing and test cells are classified according to their C system and A-B-O system phenotypes to illustrate the types of cross reactions involved.

Tested by bigeye RBC number	Bovine normal serum C347 absorbed by bigeye RBC number						C and A-B-O phenotypes of test RBC	
	704	694	702	653	695	Unabs.	C	A-B-O
724	.	.	.	.	.	.	"_"	A
725	.	.	.	.	.	+++	"_"	O
726	+++	+++	.	.	+++	+++	C_3	B
728	.	.	+++	.	+++	+++	C_2	O
729	+++	+++	+++	.	+++	+++	C_2	AB
695	.	.	.	.	.	+++	C_3	O
C	C_1	C_1	C_3	C_1	C_3		C and A-B-O phenotypes of absorbing RBC	
A-B-O	O	A	B	B	O			

5.1.3 Other factors

There are several additional blood factors which are recognized, in bigeye, by the agglutinating action of saline extracts of the following legume seeds: the soy bean (Glycine max), the common bean (Phaseolus vulgaris), and seeds of the trees Caragana arborescens and Virgilia divaricata. These blood factors appear to be independent and are not now recognized as part of any known blood group system.

5.2 The skipjack tuna

Two blood group systems and a variety of individual blood factors are recognized in skipjack tuna.

5.2.1 The C system

The blood factor C_3 detected by heteroagglutinins found in bovine normal sera is the only blood factor in the C system of skipjack observed by us. Only two classes of individuals in the C system are recognized, C_3-positive and C_3-negative.

5.2.2 The B system

The blood factors E, K_1, and K_2 form a pattern of related reactions in skipjack which we have named the B system.

E-positive erythrocytes are recognized by the agglutinating action of saline extracts of Virgilia seeds. The two blood factors K_1 and K_2 are recognized by the agglutinating action of absorbed and unabsorbed rabbit immune serum R-60. The factors K_1 and K_2 exhibit a regular subtyping relationship, demonstrable in phenotype patterns and absorption results. Table VI gives the numbers of individuals observed in the three patterns formed by the K set of reactions in the B system. Table VII shows the results of absorbing rabbit anti-skipjack immune serum (R-60) by selected individual skipjack bloods. Cells similar to 992, 993, and 997 absorb all detectable antibodies from R-60. Bloods similar to 994, 995 and 1000 absorb a fraction of the antibodies from R-60 but fail to absorb that fraction which reacts with 992, 993, and 997. Bloods of the first group are called K_1. Bloods of the second group are called K_2. Cells

Table IV
Absorption of the anti-A and anti-B reagents by A, B, AB, and O bigeye bloods to demonstrate typical cross reactions. Reagents pre-absorbed to remove anti-C fractions.

Tested with bigeye RBC number	Anti-A reagent absorbed by selected bigeye blood number						A-B-O phenotypes of test RBC
	820	821	825	834	830	Unabs.	A-B-O
820	.	.	.	.	.	.	O
821	.	.	.	.	.	.	B
834	+++	+++	+++	.	.	+++	A
830	+++	+++	+++	.	.	+++	AB
A-B-O	O	B	B	A	AB		A-B-O phenotypes of absorbing RBC

Tested with bigeye RBC number	Anti-B reagent absorbed with selected bigeye blood number						A-B-O phenotypes of test RBC
	820	821	825	834	830	Unabs.	A-B-O
820	.	.	.	.	.	.	O
825	+++	.	.	+++	.	+++	B
834	.	.	.	.	.	.	A
830	+++	.	.	+++	.	+++	AB
A-B-O	O	B	B	A	AB		A-B-O phenotypes of absorbing RBC

Table V
The application of Bernstein's formula to data collected from 427 bigeye from Hawaiian waters

Phenotype	Individuals observed	
	Number	Percent
A	42	9.8
B	56	13.1
O	319	74.7
AB	10	2.3
	427	

Bernstein's formula states that:

$$\sqrt{\bar{A} + \bar{O}} + \sqrt{\bar{B} + \bar{O}} - \sqrt{\bar{O}} = 1$$

Therefore, given the above data we observe that:

$$\sqrt{.098 + .747} + \sqrt{.131 + .747} - \sqrt{.747} = .992$$

Table VI
Classification of 1,014 skipjack by means of anti-K_1 and anti-K_2 reagents to show the pattern of relationships between K_1 and K_2 bloods

Reagent		Number of Individuals
Anti-K_1	Anti-K_2	
+++	+++	523
.	+++	268
.	.	223
+++	.	0
		1,014

Table VII
Absorption of rabbit anti-skipjack immune serum R-60 by selected cells to demonstrate the pattern of absorptions of the blood factors K_1 and K_2 in the B system.

Tested with skipjack RBC number	Rabbit anti-skipjack serum R-60 absorbed by skipjack RBC number								
	992	993	997	994	995	1000	939	941	Unabs.
992	.	.	.	+++	+++	+++	+++	+++	+++
993	.	.	.	+++	+++	+++	+++	+++	+++
997	.	.	.	+++	+++	+++	+++	+++	+++
994	.	.	.	.	.	.	.	.	+++
995	.	.	.	.	.	.	.	.	+++
1000	.	.	.	.	.	.	.	.	+++
939	.	.	.	.	.	.	.	.	.
941	.	.	.	.	.	.	.	.	.

similar to 939 and 941 do not agglutinate in either K_1 or K_2 reagents. Absorption results with these cells are similar to those with bloods 994, 995, and 1000 in that all K_2 fractions are removed.

Table VIII lists the number of individuals observed in the six patterns formed by the E reaction and the K set of reactions. The E and K relationships will be commented on in the discussion.

5.2.3 Other blood factors

The saline extracts of legume seeds described in the section on bigeye also detect blood factors in the skipjack. None of these factors appear to be important to subpopulation research except the blood factor E (mentioned above) detected by Virgilia divaricata extracts.

5.3 The albacore tuna

Albacore bloods (807) from a variety of localities--Japan, New Caledonia, North America (west coast), Samoa, and South Africa (south coast)--have been examined. In the C system both blood factors C_2 and C_3 have been recognized, while the blood factor C_1 has not yet occurred in samples tested.

Several additional blood factors are also recognized both by immune reagents and by the extracts of legume seeds. These blood factors have not yet been assigned to a particular blood group system. It is probable that the A-B-O system described for bigeye also occurs in albacore, as anti-A and anti-B reagents cross-react with albacore erythrocytes. However, these sera also contain additional cross-reactive antibodies which must be removed before albacore bloods may be rigorously classified in an A-B-O relationship.

The G_1-G_2 set of relationships, detected by tilapia immune sera (Sprague and Nakashima, 1961), has not been studied further as the volume of reagent obtainable from tilapia was so small as to be uneconomical.

Table VIII

Classification of 1014 skipjack individuals with respect to the six patterns formed by their reaction to reagents E, K_1, and K_2 of the B system

Reagent			Number of individuals
"Anti"-E	Anti-K_1	Anti-K_2	
+++	+++	+++	13
+++	.	+++	125
+++	.	.	203
.	+++	+++	510
.	.	+++	143
.	.	.	20
			1014

Extracts of legume seeds also detect albacore blood factors, but as yet they have not provided useful data for subpopulation studies.

5.4 The yellowfin tuna

Blood factors C_1, C_2, and C_3 in the C system, as well as individual blood factors Y, H, A-like, and B-like are detected in yellowfin by reagents obtained from animal sera.

The legume extracts used with bigeye also detect individual blood factors in the yellowfin. The legume *Lathyrus* sp., supplied by Mr. Klawe of the Inter-American Tropical Tuna Commission, shows promise as an effective reagent for yellowfin subpopulation studies.

6 SKIPJACK POPULATION STUDIES

Some preliminary studies of tunas collected from a variety of geographic localities have been made, however, the number of samples tested or, in some cases, the reagents available for testing have been too few for us to report in detail studies of tuna other than the skipjack.

Skipjack samples were collected and tested with reagents E, K_1, K_2, A, D, and C_3 in the vicinity of Hawaii (21° N, 158°W), the Marquesas (9° S, 140°W), the Tuamotu (16° S, 146° W), and the Society Is. (16° S, 151° W).

Of the reagents used, only those of the B system have been useful in characterizing populations from different geographic areas. Of the B system reagents, only the K set of reagents was reliable enough to draw reasonably accurate inferences relative to genetic rather than serological variables. Table IX shows the frequency of occurrence of the K phenotypes in the B system in each of the areas sampled. Table X shows the same data arranged in such a way that the 99 percent confidence limits of the observed frequency may be compared.

There were several significantly different proportions of K-phenotypes found (Table X). For example the samples from the Marquesas Is. and the Hawaiian Is. are significantly different at the 1 percent level in respect to the frequencies of both phenotypes, K_1 and "__".

Summarizing the data shown in Tables IX and X, we interpret these data as providing evidence for the occurrence of at least three reproductively isolated populations of skipjack in the areas sampled. In our opinion, at least three reproductively isolated populations have been sampled, but we cannot exclude on the basis of the present data the unlikely possibility that some mixture of two populations has occurred in such a way as to yield the proportions observed. The most likely situation is that each of three areas--Hawaiian Is., Marquesas Is., and Society-Tuamotu Is.--is represented by a characteristic biological subpopulation, or subpopulations. There is the possibility that for any single area there are seasonally or biologically distinct populations which occur in the area that are not represented by our samples. (See Marr and Sprague, in press, for a discussion of hypothetical situations of this sort.)

7 DISCUSSION

7.1 Serological studies

A variety of blood factors first recognized in one species are found in additional species as they are tested. The relationships between the blood factors often fall into some sort of familiar serological pattern such as regular subtyping

Table IX
The relative numbers of individual skipjack in samples from four geographic areas, classified according to the three phenotypes obtained by testing with anti-K reagents of the B system

		Phenotype					
		K_1		K_2		" __ "	
Sampling area	Total number	Number observed	Proportion in percent	Number observed	Proportion in percent	Number observed	Proportion in percent
Hawaiian Is.	234	154	66	74	32	6	3
Marquesas Is.	250	83	33	67	27	100	40
Tuamotu Is.	360	193	54	81	23	86	24
Society Is.	170	93	55	46	27	31	18

Table X
The observed K phenotype proportions of skipjack (see Table IX) listed by area of capture tabulated with the 99-percent confidence limits of the observed proportion (compare vertical columns, or phenotypes by area)

	Phenotype					
	K_1		K_2		" __ "	
Sampling area	Observed proportion	99% confidence limits of observed proportion	Observed proportion	99% confidence limits of observed proportion	Observed proportion	99% confidence limits of observed proportion
Hawaiian Is.	66	58 to 74	32	24 to 39	3	0 to 5
Marquesas Is.	33	26 to 38	27	20 to 34	40	32 to 48
Tuamotu Is.	54	47 to 60	23	17 to 28	24	18 to 30
Society Is.	55	45 to 65	27	19 to 36	18	11 to 26

relations, A-B-O, or MN, etc. Some examples of this sort follow in the discussion of the C system and A-B-O system of bigeye. Sometimes, however, no known pattern exists to explain the observations; the relationship of the blood factor E to K_1 will provide an example of such a case, and is worth documenting if for no other reason than to caution the unwary.

7.1.1 The C system

The C system blood factors C_1, C_2, and C_3 occur in both bigeye and yellowfin tuna. The blood factors C_2 and C_3 occur in albacore, but C_1 has not yet been found. The blood factor C_3 is the only member of this system found in skipjack. Because blood factors of the C system have been found in all tuna studied and because there is considerable variation as to the particular blood factor represented in a given species, this blood group system may eventually provide some useful information on the taxonomic relationships of the tunas.

7.1.2 The A-B-O system

The A-B-O system of bigeye is of particular interest to us because it is the first example in our laboratory of a blood group system which conforms to the expectations of the Hardy-Weinberg Law. The importance of the ability to carry out an analysis by means of the Hardy-Weinberg Law has been discussed elsewhere (Marr and Sprague, in press).

Blood group systems having the general form of the classical A-B-O groups of man have been reported for several species of fishes.

Studies of the freshwater brown bullhead (Ictalurus nebulosus) have shown an A-B-O system detected by the presence of isoagglutinins (Cushing, 1952). The Tg system of albacore (Suzuki, et al., 1958, 1959) also forms such a pattern (Marr and Sprague, in press). The S system of the spiny dogfish (Squalus acanthias) has been shown to be of the A-B-O pattern (Sindermann and Mairs, 1961). These authors present genetic evidence of the inheritance of the blood factors of the S system by means of a comparison of the blood types of female dogfish and their unborn progeny. Such studies are of great value to us because they formally demonstrate the applicability of well known genetic principles, chiefly derived from studies of man and of domestic and laboratory animals, to the study of pelagic fishes.

The two reagents, anti-A and anti-B, which delineate the A-B-O system of bigeye bloods also contain antibody fractions which cross-react with albacore and yellowfin, and as these species are studied further they may prove to be amenable to Hardy-Weinberg analysis.

Skipjack bloods do not cross-react with any of the antibody fractions contained in anti-A or anti-B sera.

7.1.3 The B system

The blood factors of the B system, K_1 and K_2, are recognized only in the skipjack. The blood factor E recognized in skipjack by Virgilia extracts falls within the B system. The blood factor E seldom occurs in bloods that are K_1-positive (Table VIII).

A variety of absorption experiments performed by us to clarify this relationship have shown that more than one reactive fraction is present in the saline extracts of Virgilia divaricata seeds which produce the E reagent. However, these experiments rather than clarifying the relationship between K_1 and E have only served to deepen our perplexity concerning the nature of the fluids producing E reactions.

7.1.4 Other blood factors

The miscellaneous immune reagents which recognize the blood factors Y and H have only recently been developed, and will not be discussed, nor will we discuss a variety of other blood factors detected by legume seed extracts.

7.2 Population studies

Our initial comparisons between skipjack captured in different geographic localities utilized the E reagent (Sprague and Nakashima, MS.). In that study we observed in the sample from the Tuamotu Is. a very low frequency (.038) of occurrence of E-positive skipjack. In the data reported here (Table IX) we were unable to repeat this observation. Several potential reasons for this occur to us, such as sampling error, errors in experimental technique, or the existence of a real but ephemeral population of skipjack. However, we do not have any rational method of choosing among these alternatives, and we must at present regard this observation as an enigma.

The general development of reagents which define blood group systems amenable to Hardy-Weinberg analysis will minimize the difficulties of interpreting the results of utilizing such troublesome fluids as the E reagent and will also make it possible to give a critical account of whether or not there is "mixing" and what the nature of various potential mixtures of individuals from different populations might be.

8 SUMMARY

Initial studies of the serology of albacore, bigeye, skipjack, and yellowfin tunas are discussed. The discovery in bigeye of a blood group system containing two blood factors, A and B, which form four phenotypes A, B, AB, and O is noted, and gene frequency estimates are calculated consonant with the hypothesis that the system is determined by the inheritance pattern of three allelic genes. The importance of being able to study such systems for subpopulation analysis is pointed out.

The relationships of several other blood factors within the four tunas studied were discussed and the K set of blood factors in the B system of skipjack was analyzed. This system provided evidence for reproductive isolation between at least two and probably three subpopulations in the area of four island groups: Hawaii, the Marquesas, the Tuamotu, and the Society Is.

Experience Paper No. 23

TUNA LANDINGS AND PRODUCTION 1916 to 1961

By

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Abstract

California tuna catch and production are compared with those of the United States and the world. Japan led all other world countries in tuna landings from 1947 - 60, but was outstripped by the United States in production during the same period. Within the United States, California industry accounted for 92 percent of all tuna landings and 83 percent of all canned tuna. California shipments and case pack have both been increasing since 1916. Shipments have been relatively unimportant to the overall poundage in California. Six species: albacore, bigeye, bluefin tuna, bonito, skipjack, and yellowfin tuna have contributed to the bulk of California landings, but small quantities of Australian bluefin, black skipjack, oriental tuna, and Atlantic bluefin tuna have also been processed.

THONS: QUANTITES DEBARQUEES ET PRODUCTION DE CONSERVES 1916 à 1961

Résumé

Les chiffres relatifs aux prises de thons et à la production de conserves en Californie sont comparés avec ceux qui concernent les Etats-Unis d'Amérique et l'ensemble du monde. De 1947 à 1960, le Japon est dèmeuré en tête pour les quantités de thons mises à terre, mais a été devancé par les Etats-Unis pendant la même période du point de vue de la production. Aux Etats-Unis, l'industrie californienne a figuré pour 92 pour cent dans le total des quantités débarquées et pour 83 pour cent dans le total des conserves de thon. Depuis 1916, tant la production de conserves que les expéditions sont en expansion en Californie, ces dernières ne représentant toutefois qu'une fraction relativement négligeable du tonnage global. Le gros des apports californiens est fourni par six espèces: germon, thon obèse (*Parathunnus sibi*), thon rouge, pélamide (*Sarda chilensis*), bonite à ventre rayé et thon à nageoires jaunes, mais l'industrie traite également de faibles quantités de thon rouge d'Australie (*Thunnus maccoyii*, *Kishinoella tongoll*), de thonine (*Euthynnus lineatus*), de thon rouge "oriental" (*Thunnus orientalis*) et de thon rouge de l'Atlantique (*Thunnus thynnus*).

DESEMBARQUES Y PRODUCCION DE ATUN 1916 a 1961

Extracto

Las capturas y la producción de atún en California se comparan con las de los Estados Unidos y con las mundiales. El Japón aventajó a todos los demás países en los desembarques de atún desde 1947 a 1960 pero fue superado por los Estados Unidos en cuanto a producción durante el mismo período. Dentro de los Estados Unidos correspondió a la industria de California el 92 por ciento de todos los desembarques de atún y el 83 por ciento de todo el atún en conserva. Los embarques y producción de atún enlatado en California han venido aumentando desde 1916. Los embarques han sido relativamente poco importantes en comparación con la cantidad total producida en California. A formar la mayor proporción de los desembarques de California han contribuído seis especies: albacora, patudo, atún de aleta azul, bonito, barrilete y atún de aleta amarilla, aunque también han sido industrializadas pequeñas cantidades de atún de aleta azul australiano, barrilete negro, atún oriental y atún de aleta azul del atlántico.

1 HISTORICAL ACCOUNT

World tuna landings annually are becoming increasingly important, and the United States and California play major roles in utilizing this valuable resource. We have attempted to show this by summarizing California landings and production and comparing them to other states within the United States, and the world.

Japan led all other world countries in tuna landings during the 14 years 1947-60, but was outstripped by the United States in production during the same period (Fig. 1). The United States gained the lead in production from the added volume of frozen fish imported from Japan and South American countries for canning.

California need not be apologetic for hosting the World Tuna Meeting, since 92 percent of the total United States landings has been unloaded at our ports and 83 percent of all tuna has been packed by our plants (Fig. 2).

California tuna and bonito landings have included albacore (*Thunnus germo*), Pacific bigeye tuna (*Parathunnus sibi*), bluefin tuna (*Thunnus saliens*), bonito (*Sarda chiliensis*), skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Neothunnus macropterus*). The California case pack (Fig. 2) includes these six species plus small amounts of Australian bluefin (*Thunnus maccoyii*, *Kishinoella tonggol*), black skipjack or little tuna (*Euthynnus lineatus*), oriental tuna (*Thunnus orientalis*) and Atlantic bluefin tuna (*Thunnus thynnus*).

Landings and shipments have generally increased since 1916 and the case pack has followed a similar trend (Fig. 3, Table VII).

The tuna fishery of California, through 1926, was in its infancy (Fig. 4). With fleet expansion, the catch rose to a peak of 203 million pounds in 1940. The fishery failed during the Second World War (1942-45) because larger tuna vessels were taken over by the government and restrictions imposed on those remaining. Following the war, the fleet grew rapidly; new boats were added and navy surplus vessels were converted. With this impetus, the tuna catch rose to 372 million pounds in 1950.

Tuna landings and shipments of 434 million pounds in 1960 (bonito included) were worth $56 million and made this California's most valuable fishery. According to our published records, this was 62 percent of the weight and 80 percent of the total value of all species.

During the 45 years 1916-61, California fleet landings made up 85 percent of the state's tuna fishery and shipments made up the remainder (Fig. 4). Shipments or imports were relatively unimportant to the fishery prior to 1950, but after that they increased rapidly to reach a maximum in 1959 when they amounted to 41 percent. Frozen yellowfin, skipjack and albacore have been the main species entering our ports from Japan and Peru to supplement California fleet landings (Tables I, II, and III). Small amounts of unclassified tuna (from both shipments and landings) were grouped into a miscellaneous category (Table VI) rather than leave them out.

California species in decreasing importance by pounds in 1961 were yellowfin, skipjack, albacore, bluefin and bonito (Tables I - V).

2 ACKNOWLEDGEMENT

Our biostatistical staff and those of other countries routinely compile fishery data from day to day. Their ever-present, important work usually goes unheralded by the scientists who constantly refer to their carefully compiled figures. We, therefore, wish to acknowledge our clerks, key punch and tabulating machine operators who have toiled many hours to make these statistics available throughout the years.

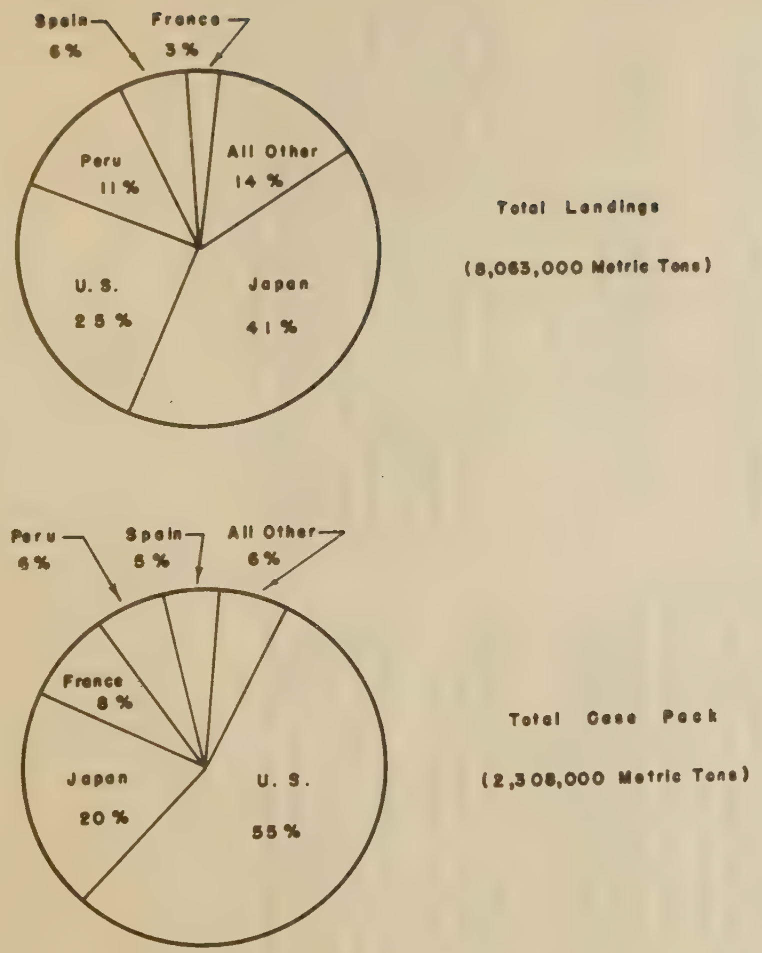

Fig. 1 World tuna catch and production, 1947 to 1960

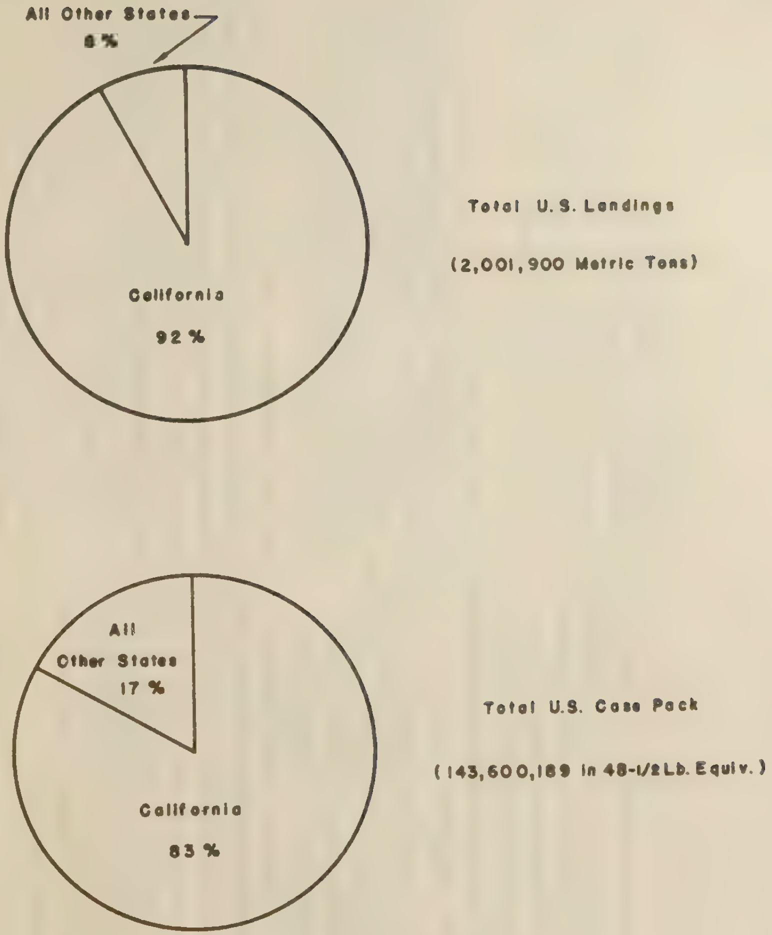

Fig. 2 Comparison of California tuna catch and production to remaining states within the United States, 1947 to 1960

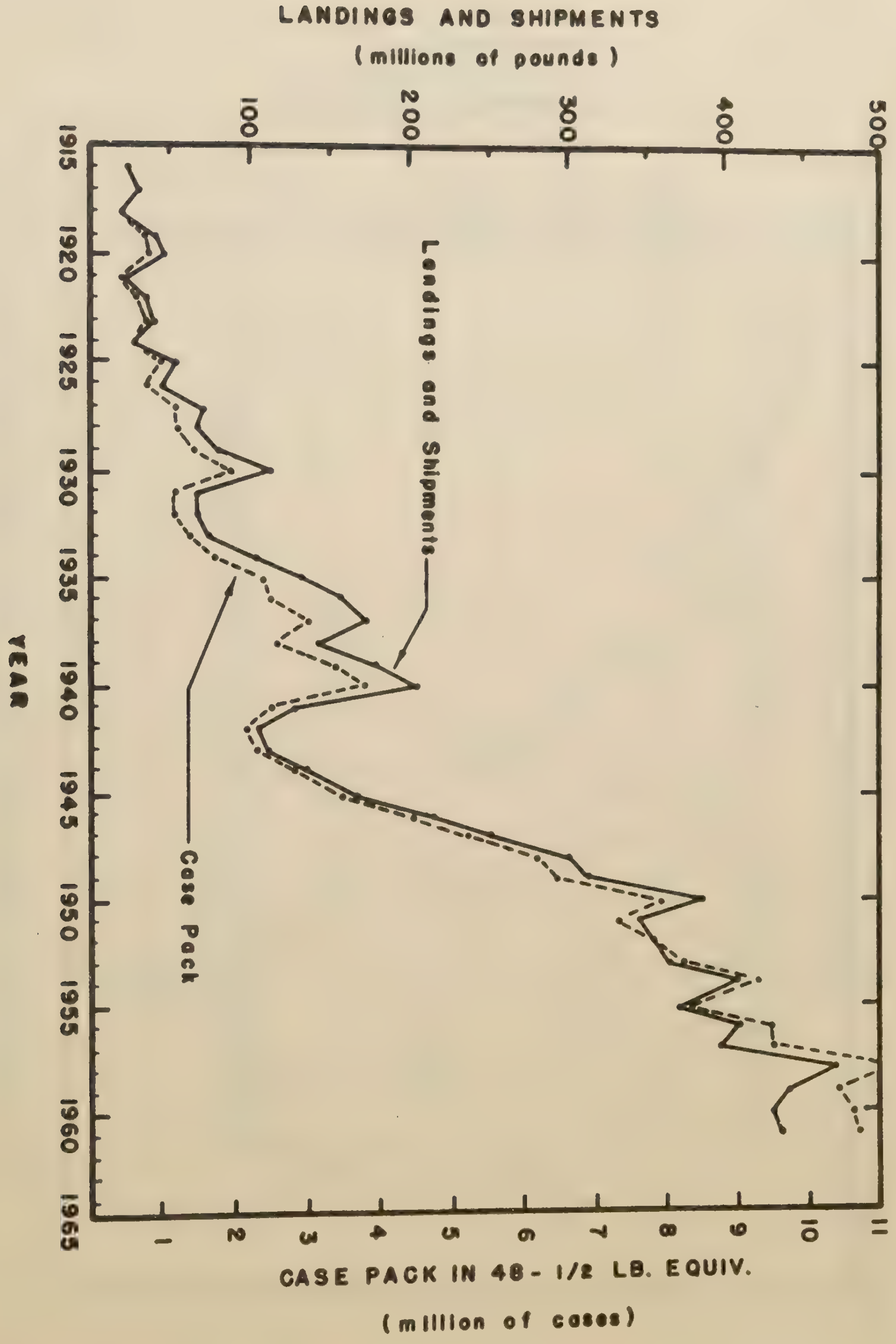

Fig. 3 California tuna catch and production, 1916 to 1961

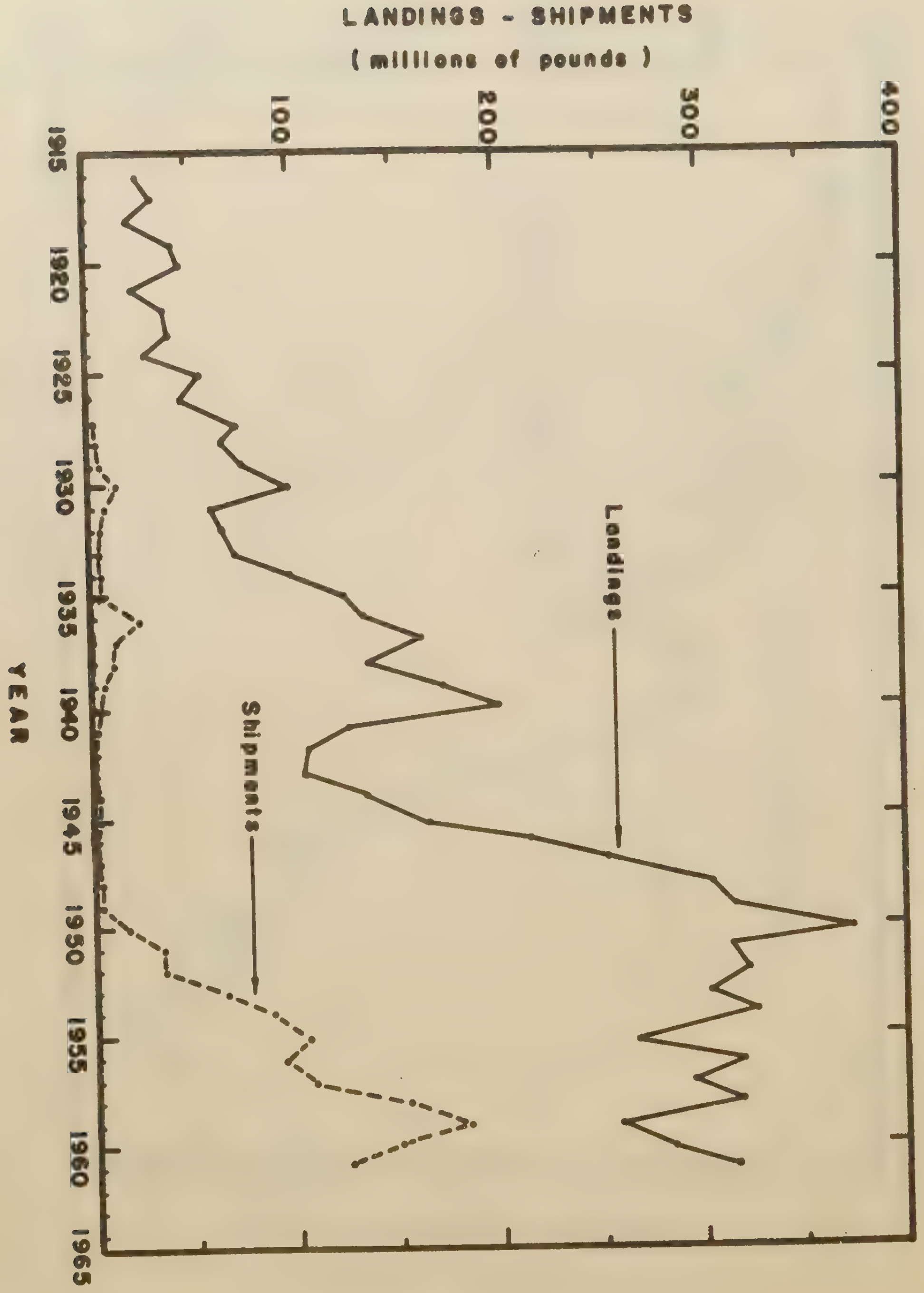

Fig. 4 California tuna landings and shipments, 1916 to 1961

TABLE I.

YELLOWFIN (*Neothunnus macropterus*)

CALIFORNIA LANDINGS AND SHIPMENTS, 1916-1961

(Thousands of Pounds)

Year	Landings	Shipments			Total Landings & Shipments
		Parts & Pieces	Whole Fish	Total	
1916	...	...	...	...	...
1917	...	...	...	...	...
1918	...	...	...	...	...
1919	348	...	...	...	348
1920	1,965	...	...	...	1,965
1921	1,297	...	...	...	1,297
1922	7,405	...	...	...	7,405
1923	10,837	...	...	...	10,837
1924	3,063	...	...	...	3,063
1925	13,238	...	...	...	13,238
1926	12,565	...	...	...	12,565
1927	25,934	...	...	...	25,934
1928	32,253	...	...	...	32,253
1929	37,445	...	...	...	37,445
1930	56,654	...	...	4	56,658
1931	36,579	...	...	2	36,581
1932	36,923	...	...	...	36,923
1933	51,076	...	...	...	51,076
1934	60,913	...	...	224	61,137
1935	72,294	...	...	...	72,294
1936	78,352	...	...	9	78,361
1937	91,522	...	...	884	92,406
1938	78,288	...	...	75	78,363
1939	110,418	...	...	...	110,418
1940	113,760	...	...	138	113,898
1941	76,665	...	...	37	76,702
1942	41,467	...	...	...	41,467
1943	49,261	...	...	...	49,261
1944	63,144	...	...	...	63,144
1945	87,331	...	...	...	87,331
1946	127,247	...	...	...	127,247
1947	150,389	...	...	70	150,459
1948	191,724	...	...	...	191,724
1949	184,524	...	...	1,088	185,612
1950	182,316	...	...	8,130	190,446
1951	160,246	...	...	13,422	173,668
1952	178,437	41	7,039	7,080	185,517
1953	132,086	1,529	6,930	8,459	140,545
1954	119,402	1,365	28,337	29,702	149,104
1955	122,292	1,551	38,975	40,526	162,818
1956	149,281	15,778	38,826	54,604	203,885
1957	136,956	25,657	19,429	45,086	182,042
1958	123,419	58,742	35,914	94,656	218,075
1959	108,370	71,086	31,536	102,622	210,992
1960	189,307	60,185	23,156	83,341	272,648
1961 *	191,855	...	...	70,456	262,311

*Preliminary figures.

TABLE II.

SKIPJACK (*Katsuwonus pelamis*)

CALIFORNIA LANDINGS AND SHIPMENTS, 1916-1961

(Thousands of Pounds)

Year	Landings	Shipments			Total Landings & Shipments
		Parts & Pieces	Whole Fish	Total	
1916	...	...	...	...	...
1917	...	...	...	...	...
1918	3,023	...	...	...	3,023
1919	6,892	...	...	...	6,892
1920	7,957	...	...	...	7,957
1921	1,135	...	...	...	1,135
1922	11,858	...	...	...	11,858
1923	11,462	...	...	...	11,462
1924	3,774	...	...	...	3,774
1925	14,222	...	...	...	14,222
1926	20,951	...	...	...	20,951
1927	33,806	...	...	...	33,806
1928	15,948	...	...	...	15,948
1929	27,007	...	...	60	27,067
1930	20,486	...	...	...	20,486
1931	16,507	...	...	...	16,507
1932	21,637	...	...	...	21,637
1933	16,687	...	...	406	17,093
1934	14,830	...	...	1,579	16,409
1935	17,197	...	...	2,607	19,804
1936	27,006	...	...	2,265	29,271
1937	47,104	...	...	7,595	54,699
1938	22,654	...	...	3,499	26,153
1939	30,121	...	...	1,066	31,187
1940	56,650	...	...	260	56,910
1941	25,585	...	...	122	25,707
1942	38,735	...	...	...	38,735
1943	28,892	...	...	...	28,894
1944	30,037	...	...	...	30,037
1945	33,348	...	...	...	33,348
1946	41,088	...	...	...	41,088
1947	52,462	...	...	...	52,462
1948	58,771	...	...	1	58,772
1949	78,522	...	...	53	78,575
1950	124,819	...	...	3,262	128,081
1951	115,887	...	...	2,751	118,638
1952	84,736	...	...	4,156	88,892
1953	122,306	...	...	8,348	130,654
1954	153,756	...	...	15,708	169,464
1955	101,891	...	...	18,634	120,525
1956	120,153	161	15,681	15,842	135,995
1957	90,548	1,520	19,368	20,888	111,436
1958	122,767	304	25,087	25,391	148,158
1959	98,481	363	47,366	47,729	146,210
1960	46,304	8,610	19,885	28,495	74,799
1961*	65,403	...	...	21,345	86,748

*Preliminary figures.

TABLE III.

ALBACORE (*Thunnus germo*)

CALIFORNIA LANDINGS AND SHIPMENTS, 1916-1961

(Thousands of Pounds)

Year	Landings	Shipments			Total Landings & Shipments
		Parts & Pieces	Whole Fish	Total	
1916	22,899	...	...	...	22,899
1917	30,556	...	...	...	30,556
1918	7,265	...	...	...	7,265
1919	13,631	...	...	...	13,631
1920	18,877	...	...	...	18,877
1921	15,277	...	...	...	15,277
1922	13,232	...	...	...	13,232
1923	12,515	...	...	...	12,515
1924	17,695	...	...	...	17,695
1925	22,207	...	...	...	22,207
1926	2,470	...	...	...	2,470
1927	4,579	...	...	78	4,657
1928	283	...	...	3,783	4,066
1929	269	...	...	5,841	6,110
1930	283	...	...	7,006	7,289
1931	37	...	...	6,939	6,976
1932	620	...	...	2,467	3,087
1933	...	...	...	2,794	2,794
1934	94	...	...	4,193	4,287
1935	2,448	...	...	3,231	5,679
1936	946	...	...	1,510	2,456
1937	2,020	...	...	2,724	4,744
1938	6,815	...	...	6,760	13,575
1939	10,000	...	...	6,423	16,423
1940	3,941	...	...	3,137	7,078
1941	3,341	...	...	973	4,314
1942	10,621	...	...	471	11,092
1943	21,385	...	...	...	21,385
1944	18,454	...	...	2,535	20,989
1945	21,275	...	61	61	21,336
1946	18,078	...	...	...	18,078
1947	13,172	...	255	255	13,427
1948	36,473	...	1,150	1,150	37,623
1949	43,993	...	284	284	44,277
1950	61,746	...	4,378	4,378	66,124
1951	30,915	...	17,521	17,521	48,436
1952	49,803	24	22,501	22,525	72,328
1953	33,836	263	45,924	46,187	80,023
1954	26,107	...	38,467	38,467	64,574
1955	29,002	31	44,814	44,845	73,847
1956	37,055	2	20,321	20,323	57,378
1957	43,525	40	39,524	39,564	83,089
1958	27,188	5	27,480	27,485	54,673
1959	32,740	567	29,175	29,742	62,482
1960	35,113	447	35,892	36,339	71,452
1961*	29,123	...	...	30,291	59,414

*Preliminary figures.

TABLE IV.

BLUEFIN (*Thunnus saliens*)

CALIFORNIA LANDINGS AND SHIPMENTS, 1916-1961

(Thousands of Pounds)

Year	Landings	Shipments			Total Landings & Shipments
		Parts & Pieces	Whole Fish	Total	
1916	...	...	...	...	...
1917	...	...	...	...	...
1918	...	...	...	...	...
1919	14,991	...	...	...	14,991
1920	10,530	...	...	...	10,530
1921	1,972	...	...	...	1,972
1922	2,811	...	...	...	2,811
1923	3,218	...	...	...	3,218
1924	3,241	...	...	...	3,241
1925	3,804	...	...	...	3,804
1926	6,526	...	...	...	6,526
1927	4,898	...	...	...	4,898
1928	13,701	...	...	...	13,701
1929	7,527	...	...	...	7,527
1930	15,599	...	...	6,322	21,921
1931	2,357	...	...	1,177	3,534
1932	460	...	...	611	1,071
1933	324	...	...	236	560
1934	18,292	...	...	66	18,358
1935	25,173	...	...	...	25,173
1936	18,925	...	...	...	18,925
1937	12,694	...	...	...	12,694
1938	17,728	...	...	...	17,728
1939	11,836	...	...	...	11,836
1940	19,970	...	...	...	19,970
1941	9,519	...	...	...	9,519
1942	12,845	...	...	...	12,845
1943	10,179	...	...	...	10,179
1944	20,344	...	...	...	20,344
1945	20,594	...	...	...	20,594
1946	22,032	...	...	...	22,032
1947	20,838	...	...	...	20,838
1948	6,529	...	...	168	6,697
1949	4,389	...	...	...	4,389
1950	2,739	...	...	108	2,847
1951	3,862	...	...	2	3,864
1952	4,577	...	...	...	4,577
1953	9,773	60	2	62	9,835
1954	21,025	...	638	638	21,663
1955	13,609	...	343	343	13,952
1956	12,626	...	163	163	12,789
1957	20,315	...	323	323	20,638
1958	30,720	...	529	529	31,249
1959	15,296	...	522	522	15,818
1960	11,952	964	264	1,228	13,180
1961*	20,882	...	...	1,122	22,004

*Preliminary figures.

TABLE V.

BONITO (Sarda chiliensis)

CALIFORNIA LANDINGS AND SHIPMENTS, 1916-1961

(Thousands of Pounds)

Year	Landings	Shipments	Total Landings & Shipments
1916	480	...	480
1917	889	...	889
1918	2,442	...	2,442
1919	3,509	...	3,509
1920	874	...	874
1921	325	...	325
1922	958	...	958
1923	1,115	...	1,115
1924	1,045	...	1,045
1925	879	...	879
1926	3,122	...	3,122
1927	1,718	...	1,718
1928	2,106	...	2,106
1929	2,919	...	2,919
1930	5,164	...	5,164
1931	3,080	...	3,080
1932	2,862	...	2,862
1933	2,252	...	2,252
1934	3,203	...	3,203
1935	7,896	...	7,896
1936	7,216	...	7,216
1937	7,808	...	7,808
1938	7,840	...	7,840
1939	9,919	...	9,919
1940	5,291	...	5,291
1941	10,827	81	10,908
1942	1,651	...	1,651
1943	2,282	...	2,282
1944	819	...	819
1945	2,714	...	2,714
1946	5,626	...	5,626
1947	13,697	...	13,697
1948	9,135	...	9,135
1949	1,829	6	1,835
1950	696	...	696
1951	777	7	784
1952	2,143	2	2,145
1953	3,103	...	3,103
1954	2,319	4	2,323
1955	137	3	140
1956	128	...	128
1957	219	...	219
1958	5,547	11	5,558
1959	3,012	...	3,012
1960	1,251	...	1,251
1961*	8,501	...	8,501

*Preliminary figures.

TABLE VI.

MISCELLANEOUS TUNA*

CALIFORNIA LANDINGS AND SHIPMENTS, 1916-1961

(Thousands of Pounds)

Year	Landings	Shipments			Total Landings & Shipments
		Parts & Pieces	Whole Fish	Total	
1916	...	...	...	...	...
1917	...	...	...	...	...
1918	6,241	...	...	...	6,241
1919	2,461	...	...	...	2,461
1920	5,483	...	...	...	5,483
1921	1,553	...	...	...	1,553
1922	692	...	...	...	692
1923	662	...	...	...	662
1924	546	...	...	...	546
1925	427	...	...	...	427
1926	261	...	...	...	261
1927-31**	...	...	...	...	...
1932	...	...	...	1,054	1,054
1933	...	...	...	899	899
1934	...	...	...	...	...
1935	...	...	...	146	146
1936	...	...	...	765	765
1937	...	...	...	524	524
1938	...	...	...	4	4
1939-49**	...	...	...	...	...
1950	...	...	...	40	40
1951	7	...	...	30	37
1952	...	...	...	...	...
1953	4	20	...	20	24
1954	...	85	1,298	1,383	1,383
1955	...	...	...	512	512
1956	...	...	...	668	668
1957	...	112	716	828	828
1958	5	1,760	3,856	5,616	5,621
1959	...	320	1,924	2,244	2,244
1960	...	217	104	321	321
1961#	...	...	...	612	612

*Includes unidentified species and Atlantic bluefin (*Thunnus thynnus*), oriental bluefin (*Thunnus orientalis*), Pacific bigeye tuna (*Parathunnus sibi*), and black skipjack (*Euthynnus lineatus*).

**No recorded landings.

#Preliminary figures.

TABLE VII.

CALIFORNIA CASE PACK OF TUNA AND BONITO

IN ½-lb. 48 EQUIVALENTS, 1918-1961

Year	Tuna (Light Meat)	Albacore (White Meat)	Bonito	Total
1918	424,786	36,895	...	461,681
1919	517,351	205,735	52,361	775,447
1920	437,423	393,121	7,751	838,295
1921	98,581	339,193	...	437,774
1922	435,417	206,820	7,979	650,216
1923	470,883	308,814	14,798	794,495
1924	496,629	116,903	8,753	622,285
1925	545,390	478,403	7,631	1,031,424
1926	691,555	59,856	43,677	795,088
1927	1,060,705	131,155	22,341	1,214,201
1928	1,089,508	106,204	19,401	1,215,113
1929	1,232,476	143,919	48,641	1,425,036
1930	1,726,697	157,379	75,266	1,959,342
1931	1,002,108	154,722	52,834	1,209,664
1932	1,053,929	72,759	46,683	1,173,371
1933	1,281,722	53,104	39,197	1,374,023
1934	1,773,634	88,615	57,054	1,919,303
1935	2,175,638	118,350	139,680	2,433,668
1936	2,342,323	61,808	116,514	2,520,645
1937	2,804,173	101,154	149,261	3,054,588
1938	2,123,147	297,714	154,516	2,575,377
1939	2,792,380	382,906	191,220	3,366,506
1940	3,618,425	155,160	109,165	3,882,750
1941	2,216,218	102,812	218,051	2,537,081
1942	1,912,926	242,203	33,163	2,188,292
1943	1,833,094	442,634	35,750	2,311,478
1944	2,420,898	447,949	8,490	2,877,337
1945	2,991,932	480,615	50,091	3,522,638
1946	4,033,874	381,271	110,617	4,525,762
1947	4,724,018	287,120	253,106	5,264,244
1948	5,272,016	800,708	171,565	6,244,289
1949	5,630,818	843,962	23,534	6,498,314
1950	6,536,419	1,437,388	12,924	7,986,731
1951	6,160,613	1,179,449	14,467	7,354,529
1952	6,028,055	1,844,079	46,582	7,918,716
1953	6,103,591	2,133,639	70,453	8,307,683
1954	7,576,309	1,727,928	45,239	9,349,476
1955	6,496,214	1,829,902	2,739	8,328,855
1956	8,025,406	1,523,302	1,605	9,550,313
1957	7,350,345	2,193,815	3,375	9,547,535
1958	9,658,923	1,484,104	109,118	11,252,145
1959	9,123,198	1,635,694	57,071	10,815,963
1960	8,799,166	1,926,356	10,739	10,736,261
1961	9,000,939	1,640,495	157,815	10,799,249

Experience Paper No. 24

GROWTH AND SEXUAL DIMORPHISM IN GROWTH OF BIGEYE TUNA (Thunnus obesus) A PRELIMINARY REPORT

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Abstract

This report covers the results of a preliminary study on growth and sexual dimorphism in the growth of bigeye tuna. The analysis was limited to data collected from the Hawaiian longline fishery from April 1960 through March 1961. From 4 to 7 normal curves were fitted to each monthly weight distribution by the probability paper method. By making several assumptions a composite figure was constructed showing the estimated growth for male and female bigeye over a five-year period. The modal weights of male and female bigeye were used to fit the von Bertalanffy growth equation. The equation describes the growth of bigeye adequately and showed that males grew faster than females after age 3 (approximately 100 lbs). For males $W_\infty = 518$, $K = 0.114$, $t_o = 1.07$, and for females $W_\infty = 364$, $K = 0.167$, $t_o = 1.06$.

THON OBESE (Thunnus obesus): CROISSANCE ET DIFFERENCES DU TAUX DE CROISSANCE SELON LE SEXE - RAPPORT PROVISOIRE

Résumé

Le présent rapport fournit les résultats d'une étude préliminaire sur la croissance et les différences du taux de croissance selon le sexe chez le thon obèse. L'étude n'a porté que sur des données fournies d'avril 1960 à mars 1961 par la pêche aux palangres dans les eaux hawaiiennes. Par la méthode du papier à échelle fonctionnelle, on a ajusté de 4 à 7 courbes normales à chacun des histogrammes donnant mensuellement la composition des prises par poids. Sur la base de plusieurs hypothèses a été établi un graphique complexe indiquant pour une période de cinq ans l'estimation de la croissance du thon obèse mâle et femelle. On a utilisé les poids modaux du thon obèse mâle et femelle dans l'équation de croissance établie par von Bertalanffy. Celle-ci fournit une description satisfaisante de la croissance du thon obèse et révèle que les mâles se développent plus vite que les femelles après l'âge de 3 ans (correspondant approximativement à un poids de 100 pounds). Pour les mâles, $W_\infty = 518$, $K = 0,114$, $t_o = 1,07$, et pour les femelles, $W_\infty = 364$, $K = 0,167$, $t_o = 1,06$.

CRECIMIENTO Y DIMORFISMO SEXUAL EN EL CRECIMIENTO DEL ATUN PATUDO (*Thunnus obesus*) INFORME PRELIMINAR

Extracto

Este informe comprende los resultados de un estudio preliminar sobre crecimiento y dimorfismo sexual en el crecimiento del patudo. El análisis se limitó a los datos recogidos de la pesquería hawaiana con palangre desde abril de 1960 a final de marzo de 1961. Se ajustaron de 4 a 7 curvas normales a cada una de las distribuciones mensuales de peso por el método del papel de probababilidad. Partiendo de varios supuestos se construyó una gráfica compuesta que mostraba el crecimiento estimado de los ejemplares machos y hembras de patudo en un período de 5 años. Los pesos modales de los machos y las hembras se utilizaron para ajustar la ecuación de crecimiento de Von Bertalanffy. Esta ecuación describe adecuadamente el crecimiento del patudo y mostró que los machos crecen más rápidamente que las hembras después de la edad 3 (aproximadamente 100 libras). Para los machos $W\infty = 518$, $K = 0,114$, $t_o = 1,o7$, y para las hembras $W\infty = 364$, $K = 0,167$, $t_o = 1,06$.

1 INTRODUCTION

A persistent feature in the size distribution of the bigeye and yellowfin (Thunnus albacares) tuna catches from the Pacific has been the predominance of males among the larger fish (Murphy and Otsu 1954, Iversen 1955, Murphy and Shomura 1955). Males begin to dominate the catch from about 122 cm. (approximately 85 pounds), and this difference in sex ratios appears to increase with size (Fig. 1).

Assuming that there are no differences in the behavioral patterns of males and females, the disproportionate sex ratios among the large fish could result from (1) differential growth between sexes, (2) differential natural mortality between sexes, or (3) a combination of differential growth and natural mortality. The growth of bigeye and the differences in growth rate between males and females are investigated in the present paper.

2 METHODS AND MATERIALS

A sampling program was initiated in April 1960 to collect catch, effort, size, and sex data on the various tunas taken by the Hawaiian longline fishery. This fishery is the only one in the United States presently catching the large tunas by the set hook-and-line method developed by the Japanese. Details of the fishery are given by June (1950) and Otsu (1954). Since the fishery is dependent upon the fresh fish market, the catch is stored in ice and trips are of short duration, each trip averaging about 9 to 10 days (Shomura 1959).

The size and sex data for bigeye tuna collected from April 1960 through March 1961 form the basis of this report. The procedures followed in handling the data were:

(1) The data were summarized by grouping individual fish weights into 5-pound categories by month;

(2) Normal curves were fitted to the monthly weight distributions by the probability paper method (Harding 1949, Cassie 1954);

(3) A composite figure was constructed by combining the modal groups to represent a single "year-class";

(4) The asymptotic size calculated by using the Walford (1946) transformation was taken as a starting point in fitting a von Bertalanffy growth equation (Beverton and Holt 1957) to the data.

3 RESULTS

The monthly weight distributions of male and female bigeye (Fig. 2) show a number of overlapping modal groups. By separating the sexes and by utilizing the probability paper method we have been able to separate four to seven modal groups. Previous studies (Iversen 1955, Kamimura and Honma 1953) have been limited to a maximum of four modal groups. The regular occurrence of the modal groups in the present study is evidence that they are real and not vagaries of sampling. Nearly all of the modal groups can be followed throughout the entire 12-month period.

In order to describe the growth of males and females and to compare their growth rates over a period longer than 12 months several assumptions were made in constructing the composite figure (Fig. 3). These assumptions and the evidence available to support them are:

(1) That the modal groups represent year-classes. This is substantiated by the progression in mean size of the modal groups with time, which is such that the mean size of a modal group is approximated by the succeeding modal group 1 year later.

(2) That there are no differences in growth rate between year-classes.

(3) That the peak spawning occurs in April. Evidence supporting an early spring spawning is the capture of several bigeye with ovaries in the late stages of maturation early in the spring of 1961.

(4) That fish entering the longline fishery as recruits in September at about 45 pounds are 17 months old.

Although there are instances of an apparent cessation in growth (modal group D, females, April-July, Fig. 2) and even an apparent "negative" growth (modal group E, females, April-July, Fig. 2), the general increase in mean size over the 5-year period (age 2 to 7,

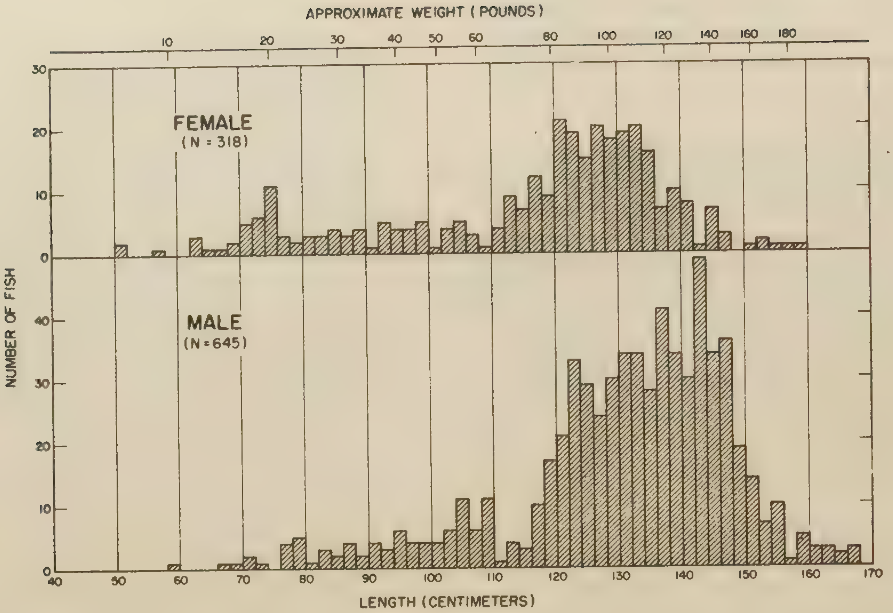

Fig. 1 Length frequency distributions of bigeye tuna from 137°-165° E. longitude taken between March 29 and May 28, 1951 (adapted from Iversen 1955)

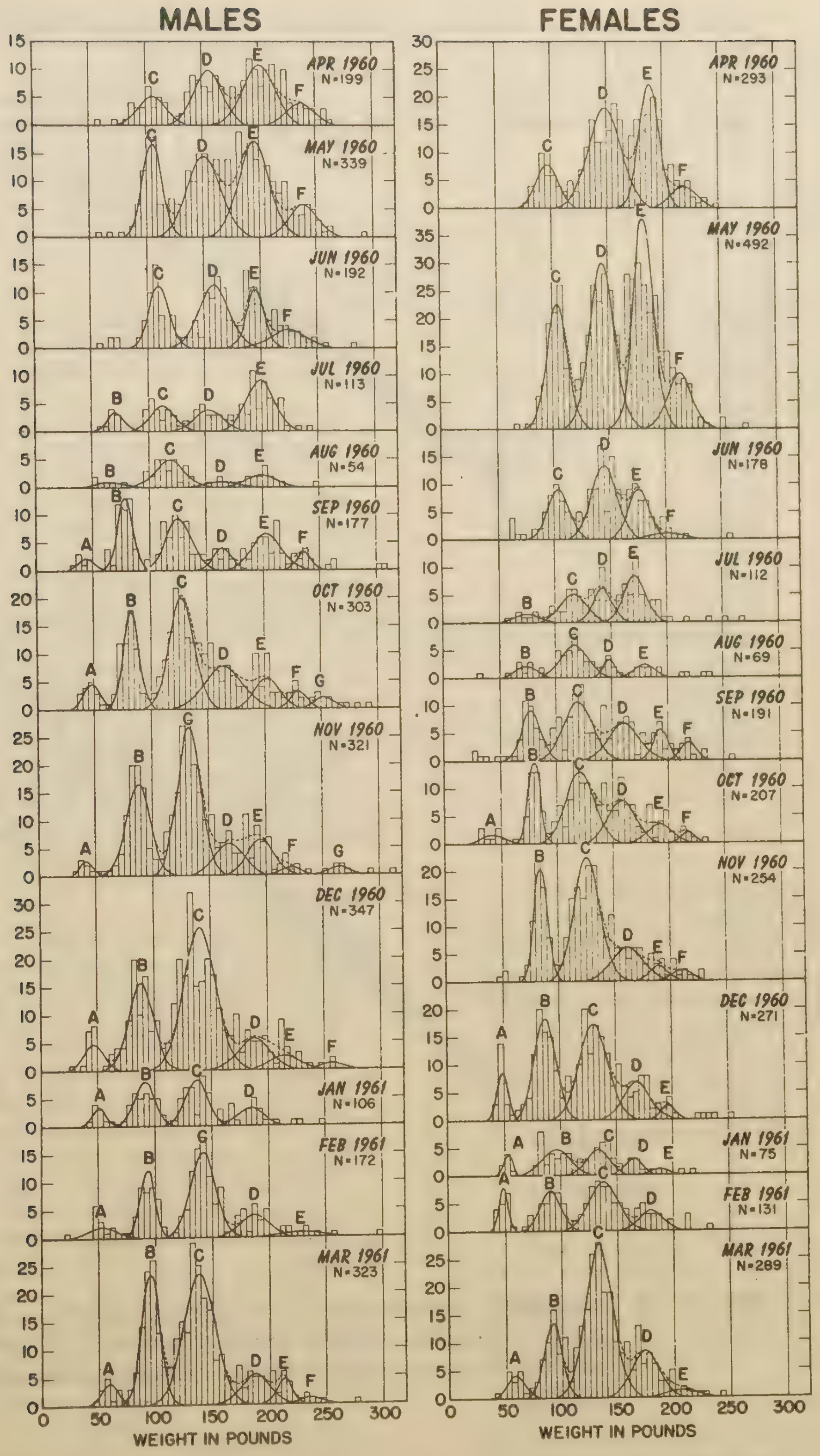

Fig. 2 Monthly weight distribution of male and female bigeye, April 1960 - March 1961

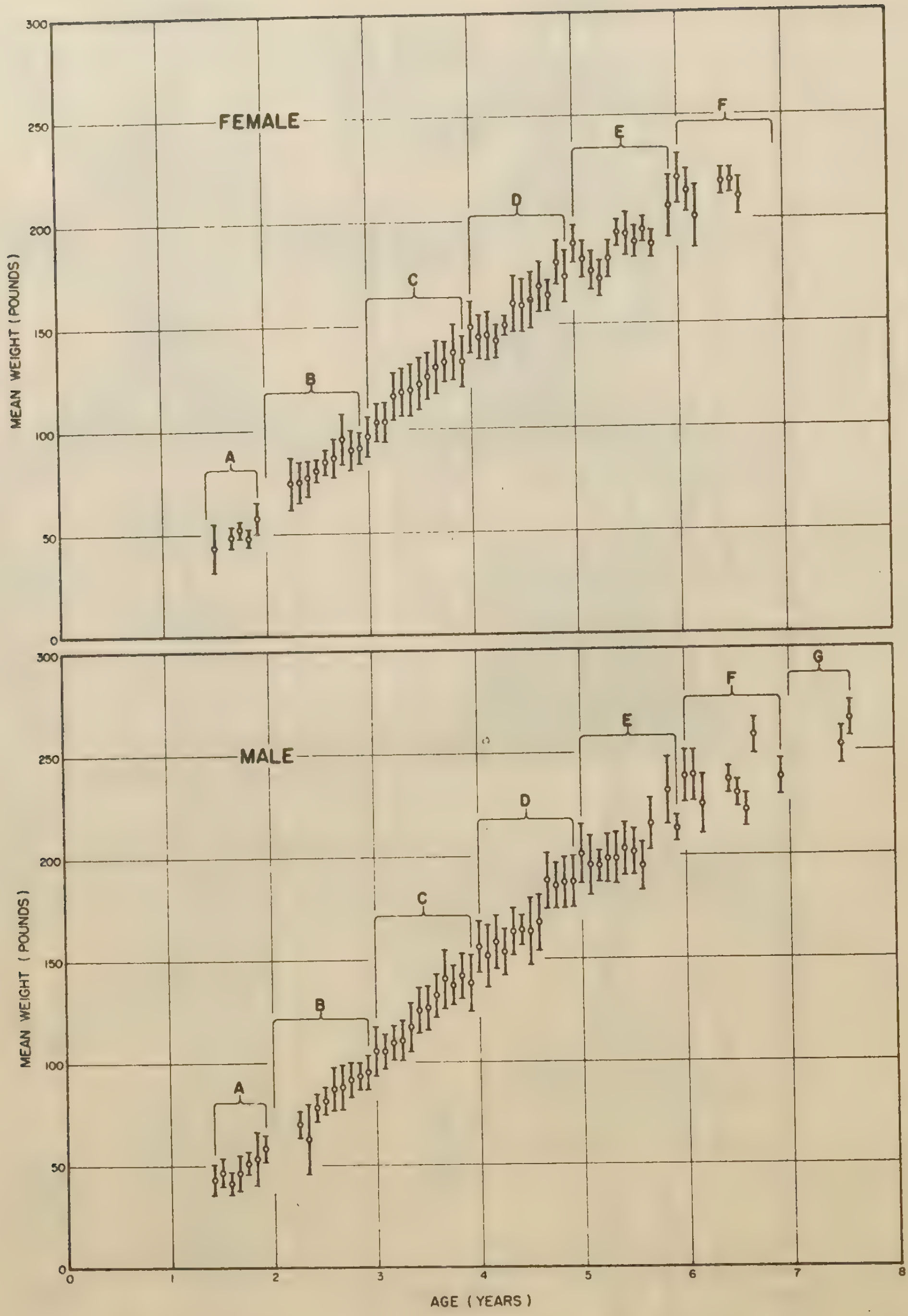

Fig. 3 A composite representation of bigeye growth. Upper panel - females, lower panel - males. Circles indicate means, heavy black lines span one standard deviation

Fig. 3) shows a growth of 200 pounds for the males and 175 pounds for the females.

A growth equation developed by von Bertalanffy was used to describe the growth of bigeye. The relationship of the growth parameters in this equation is:

$$W_t = W_\infty (1 - e^{-K(t - t_o)})$$

where:

W_t	is the size (weight in pounds) of fish at time $\underline{t}$
W_∞	is the asymptotic size (size at t_∞)
K	represents a constant which is proportional to the rate of metabolism
t_o	is the hypothetical age at which the fish would have been zero pounds if it followed the growth rate as described for later life

Only modal groups B through F were used in fitting the von Bertalanffy equation. Modal group A was eliminated because these fish are being recruited into the fishery and the calculated mean size is probably not representative of the true value for this modal group. Modal group G was eliminated because of its sporadic occurrence and the small sample size.

The values of W_∞, K, and t_o for male and female bigeye are given in Table I, and the calculated growth curves are shown in Fig. 4. The growth rates for both sexes are similar up to about 100 pounds (Table II, Fig. 4). This similarity in the early years is also indicated by the closeness of the t_o values (Table I). After age 3, the males grow faster than the females, and by the 7th year males are 25 pounds larger than females. The theoretical difference in weight is quite considerable for fish approaching the asymptotic sizes (518 pounds for males and 364 pounds for females), however, bigeye of these sizes have not been reported. Of about 6,000 bigeye sizes recorded from the central Pacific only 15 were found to be larger than 300 pounds. Thirteen of these fish were sexed and all were found to be males. The largest on record in our laboratory files is a 375 pound male.

Table I

Estimates of growth parameters for male and female bigeye

	W_∞	t_o	K
♂	517.8	1.07	0.114
♀	363.9	1.06	0.167

Table II

Weight at age of bigeye tuna as determined from von Bertalanffy's equation

	Weight (lbs.)	
Age (yrs.)	♂	♀
1.5	24.9	25.5
2.0	52.3	52.8
2.5	77.7	77.5
3.0	102.0	100.8
3.5	125.3	121.5
4.0	147.1	141.2
4.5	167.8	159.0
5.0	186.9	175.4
5.5	205.1	190.3
6.0	222.7	204.5
6.5	239.2	217.3
7.0	254.2	228.9

4 DISCUSSION

Although the present evidence supports the hypothesis of sexual dimorphism in the growth of bigeye, growth alone does not explain all of the differences noted in the size and sex distribution. Differential mortality rates may be a complicating factor. The evidence for this is (1) that the sex ratios in the smaller sizes do not show a predominance of females, and (2) the presence of an apparent "negative" growth.

5 SUMMARY

Size and sex data of bigeye tuna collected from April 1960 through March 1961 from the Hawaiian longline fishery were utilized in a study of growth and sexual dimorphism in the growth of bigeye tuna.

From four to seven modal groups were defined from each monthly weight summary by fitting normal curves to the multi-modal distributions. The probability paper method was used to fit the normal curves.

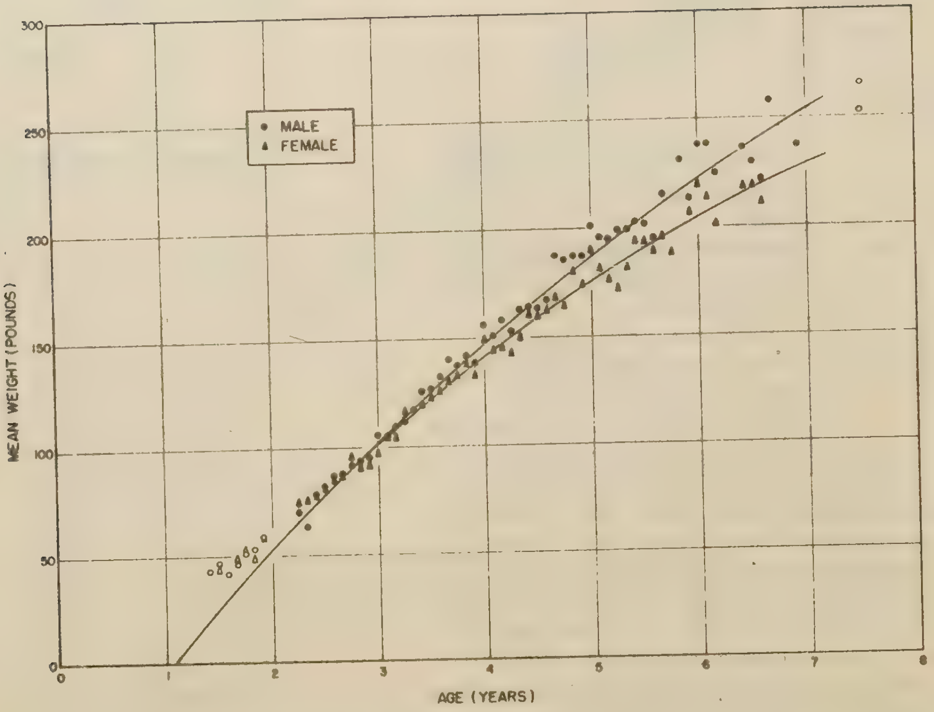

Fig. 4 A comparison of growth of male and female bigeye from Hawaiian waters, as calculated by the von Bertalanffy equation. (The points marked with open symbols were not used in the calculation of the growth curves.)

A composite figure was constructed showing the calculated mean sizes of male and female bigeye from ages 3 to 7. Males grew more rapidly than females after age 3.

The von Bertalanffy growth equation was fitted to the data. The parameters of the equation are: $W_\infty = 518$, $K = 0.114$, $t_o = 1.07$ for the males and $W_\infty = 364$, $K = 0.167$, $t_o = 1.06$ for the females.

Experience Paper No. 25

SCHOOLING BEHAVIOR WITHIN AGGREGATIONS COMPOSED OF YELLOWFIN AND SKIPJACK TUNA

By
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Abstract

Yellowfin and skipjack tuna from aggregations containing both species were studied with respect to size and schooling behavior. A conclusion was drawn that mixed aggregations of yellowfin and skipjack were the result of separate specific schools being attracted together by a common external stimulus, probably food.

RASSEMBLEMENT EN BANCS DES THONS A NAGEOIRES JAUNES ET DES BONITES A VENTRE RAYE DANS LES CONCENTRATIONS MIXTES DE CES DEUX ESPECES

Résumé

Des études portant sur la taille des poissons et sur la formation de bancs ont été effectuées sur des thons à nageoires jaunes et des bonites à ventre rayé provenant de rassemblements renfermant ces deux espèces. Il a été conclu que les concentrations mixtes de thons à nageoires jaunes et de bonites à ventre rayé provenaient de l'attraction exercée simultanément sur des bancs distincts par un stimulus externe commun, probablement la présence de nourriture.

TENDENCIA A LA FORMACION DE CARDUMENES DENTRO DE AGREGACIONES COMPUESTAS DE ATUNES DE ALETA AMARILLA Y BARRILETE

Extracto

Se estudiaron los atunes de aleta amarilla y barrilete procedentes de agregaciones compuestas por ambas especies con respecto a su tamaño y a su comportamiento gregario. Se dedujo la conclusión de que las agregaciones mixtas de atún de aleta amarilla y barrilete procedían de cardúmenes independientes que habían sido atraídos a unirse por un estímulo externo común, probablemente debido al alimento.

1 INTRODUCTION

Occurrences, of yellowfin tuna (Neothunnus macropterus) and skipjack tuna (Katsuwonus pelamis) together have been reported and studied by Orange, Schaefer, and Larmie (1957) and Broadhead and Orange (1960). They assumed both species to be in the same school. Recent underwater observations at sea on skipjack and yellowfin feeding together indicate, however, that this assumption may not be true. The objective of this study is to find out whether a simultaneous occurrence of these tunas is a single school of yellowfin and skipjack schooling with each other or a juxtaposition of two monospecific schools.

In order to avoid confusion, the author would like to note that the word aggregation is used in this study in its general sense and not as Breder (1959) defines it. It refers to groups of fish without applying any social attraction between group members.

2 SOURCES OF DATA

Body length data of skipjack and yellowfin were drawn from Table 7 of Broadhead and Orange (1960) and from records of the U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu. The former source provided data from 42 yellowfin schools, 64 skipjack schools, and 57 aggregations of mixed species composition. The latter source provided data from 26 aggregations of mixed species composition (Table I). Fourteen of these were encountered in the Tuamotu and Marquesas island groups of French Oceania, 5 in the Hawaiian Islands, 1 in the Line Islands, and 6 in the vicinity of Roca Partida in the Revilla Gigedos Islands.

Observations on the distribution and behavior of skipjack and yellowfin as they fed on live bait thrown from the stern of the Charles H. Gilbert, research ship of the Biological Laboratory, Honolulu, were made on six occasions off Roca Partida during April and May 1960 and once off Hiva Oa in the Marquesas Islands on October 24, 1961. Underwater motion picture records on 16 mm film made through the viewing facilities of the ship (described by Strasburg and Yuen, 1960) on May 12, 1960, and October 24, 1961, were analyzed for this study. Filming was done in 10-39 sec. sequences throughout the fishing period.

3 TREATMENT OF DATA AND RESULTS

3.1 Size relationships

Since yellowfin and skipjack tend to school by size (Schaefer, 1948, and Brock, 1954), fish of the two species occurring in the same school would be expected to be similar in size. The mean lengths of yellowfin, however, are longer than the mean lengths of skipjack caught in the same fishing operation by an average of 93 mm, a difference statistically greater than zero ($t = 5.835$, d.f. $= 82$, $p < 0.001$).

On the other hand, yellowfin found with skipjack are on the average smaller than those not found with skipjack (Broadhead and Orange, 1960). This indicates some size selection between species, in view of the fact that skipjack do not attain the size that yellowfin do. A plot of the mean lengths of yellowfin against the mean lengths of skipjack caught at the same time (Fig. 1) clarifies somewhat the size relationships between the two. Small yellowfin (460-490 mm mean length) were found with small skipjack (340-450 mm mean length) and larger yellowfin (490-1060 mm mean length) were found with larger skipjack (470-650 mm mean length), but no size correlation existed within these groups.

3.2 Schooling relationships

On the six occasions off Roca Partida when yellowfin were caught with skipjack, the disorderly succession in which members of both species were landed implied that they were thoroughly mixed. Whenever underwater observations were made of both species together, however, skipjack seemed to be oriented to skipjack and yellowfin to yellowfin, even with the disruption of schooling behavior by the feeding situation. Except for a few occasions the skipjack were concentrated within 2 m of the surface, while the yellowfin were concentrated below them at about 2.5-3 m. On the excepted occasions, schools of rainbow runner (Elagatis bipinnulatus) preempted the position of the skipjack, whereupon the skipjack descended to the level of the yellowfin. Although the yellowfin remained at the same level, schooling by species was apparent.

Table I

Length data of yellowfin and skipjack from the same aggregation

Date	Location	Yellowfin Sample size	Yellowfin Mean length (mm)	Skipjack Sample size	Skipjack Mean length (mm)
1/26/57	Marquesas	6	1059	29	565
1/28/57	"	25	769	4	542
2/12/57	Tuamotu	9	581	25	475
2/12/57	"	9	554	21	474
4/27/57	Hawaii	3	463	8	347
4/29/57	"	4	486	12	404
5/6/57	"	10	478	10	429
5/12/57	"	6	468	10	449
5/14/57	"	4	473	7	372
10/27/57	Marquesas	6	542	25	529
1/3/58	"	4	506	25	501
2/27/58	"	5	746	21	514
2/28/58	"	14	761	4	486
3/29/58	"	8	712	30	494
4/18/58	"	4	581	32	480
11/10/58	Line	21	665	6	606
2/2/59	Tuamotu	4	632	17	561
2/23/59	Marquesas	25	707	16	524
3/8/59	"	27	513	23	485
4/16/60	Revilla Gigedos	21	554	20	504
4/16/60	"	20	522	20	558
4/17/60	"	15	634	20	575
4/25/60	"	20	519	20	572
5/12/60	"	20	491	20	528
*5/12/60	"	6	509	10	565
*10/24/61	Marquesas	15	846	59	532

* Filmed sequences of these aggregations used in schooling behavior analysis.

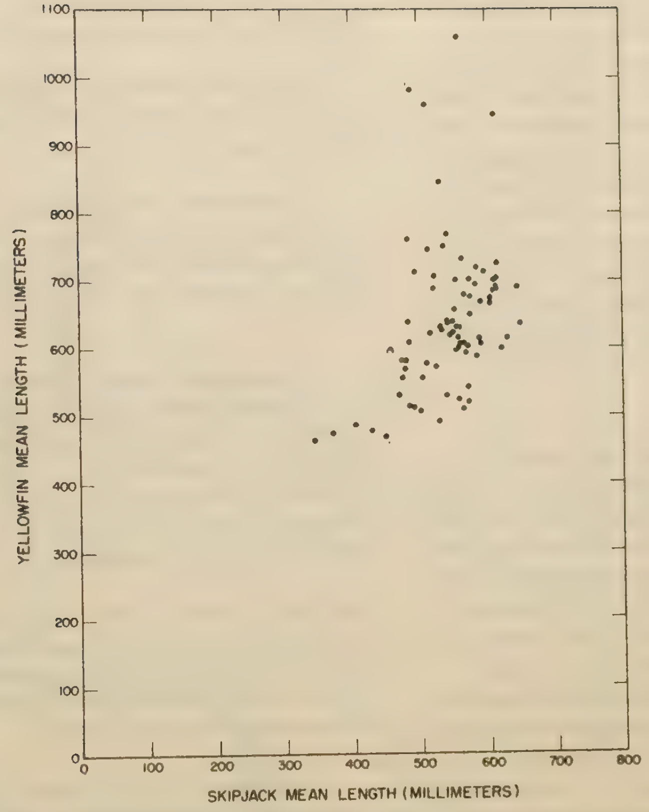

Fig. 1 Relationship of mean lengths of yellowfin and skipjack of the same aggregation.

Analysis of the underwater motion pictures provided a more objective examination of schooling behavior. If both species were schooling randomly with no selectivity towards members of their own species, a constant proportion between them would be expected from one film sequence to another. All identifiable fish on film were therefore enumerated and classified by species. A plot of the percentage of skipjack in each film sequence against time (Fig. 2) demonstrates the quantitative variability in the species composition within mixed aggregations. The total number of each species observed in an aggregation was used to calculate an average species proportion (horizontal lines in Fig. 2) for that aggregation. Wide departures from the averages (all expected numbers less than 5 excluded, $X^2 = 216.321$ and 51.875, d.f = 9 and 16, $p < 0.01$) indicate that the members of these species were not uniformly mixed, which in turn suggests that they have a tendency to be with their own.

Interspecific schooling when both species were present is not, however, precluded. To investigate schooling relationships between individuals, all identifiable groups of schooling fish as they appeared on the projection screen were classified by number in the group and species composition. Fish were considered to be schooling if their paths were parallel at any time. The relative positions and distance between fish following parallel paths did not matter as long as they appeared on the screen at the same time and no other fish were between them. In actuality the maximum observed distance between fish considered to be schooling did not exceed 1.5 m.

The percentage of each size group (2 fish, 3 fish, 4 fish, etc.) showing species homogeneity was obtained for each film sequence. The observed percentages were compared with curves of expected percentages of homogeneous groups from populations of varying proportions of two species. Comparisons for groups of two, three and four are represented in Fig. 3.

Points describing the curves of Fig. 3 are percent expressions of probabilities calculated from the following equation:

$$p = \frac{C^g_s}{C^g_{(s+y)}} + \frac{C^g_y}{C^g_{(s+y)}}$$

where:

p is the probability of obtaining a homogeneous group (either yellowfin or skipjack) of size g from all combinations of size g possible from a population of s skipjack and y yellowfin;

C^g_s is the number of ways groups of g skipjack can be formed from s skipjack;

C^g_y is the number of ways groups of g yellowfin can be formed from y yellowfin;

$C^g_{(s+y)}$ is the number of ways groups of g members can be formed from a population of $s + y$ individuals.

The value p increases towards a limit as $s + y$ approaches infinity. The curves of Fig. 3 represent the limit values of p in percent plotted against the percent equivalent of $\frac{s}{s+y}$.

The points of Fig. 3 are observed values, each point representing a film sequence. The position of each point was calculated using only those fish found in the group size concerned. For example, one sequence contained 14 pairs. Of the 28 fish involved in pairs, 8 were skipjack and 20 yellowfin giving $\frac{8}{28}$ or 28.6 percent skipjack. Nine pairs were solely yellowfin and 3 solely skipjack so that 12 pairs out of 14 or 85.7 percent were homogeneous. The number beside each point is the number of groups represented by the point.

Points above the calculated curves mean that more homogeneous groups were observed than expected, which indicates that fish tend to select members of their own species with which to school. Conversely, points below the curves mean that less homogeneous groups were observed than expected, which indicates a preference for members of the other species for schooling companions. The points above and below the curves were counted (Fig. 4) and a chi-square test applied to the pooled data. The expected number was taken as half the total number of points, since the points would be expected to be distributed equally above and below the curves if the fish showed no species selectivity in schooling. The highly significant chi-square value of 18.689 (χ^2 at $P_{.01}$ is 6.635) resulted from an excess in the direction of homogeneous groups.

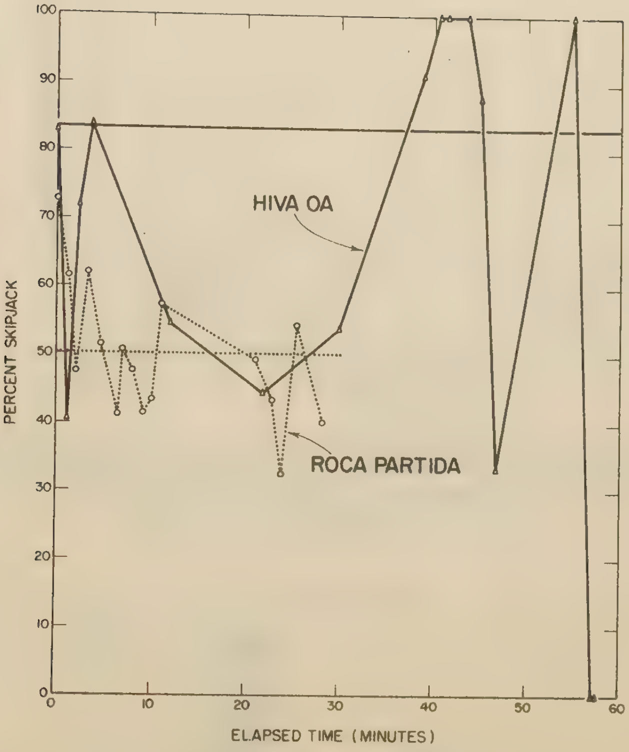

Fig. 2 Changing species proportions within mixed aggregations with time.

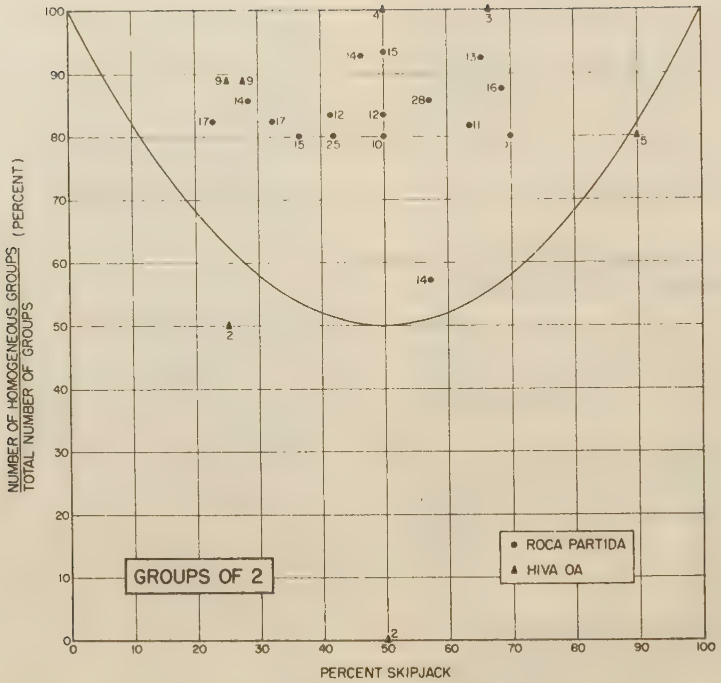

Fig. 3a Comparison of observed percentage of homogeneous groups in species mixtures of different proportions with that expected by chance.

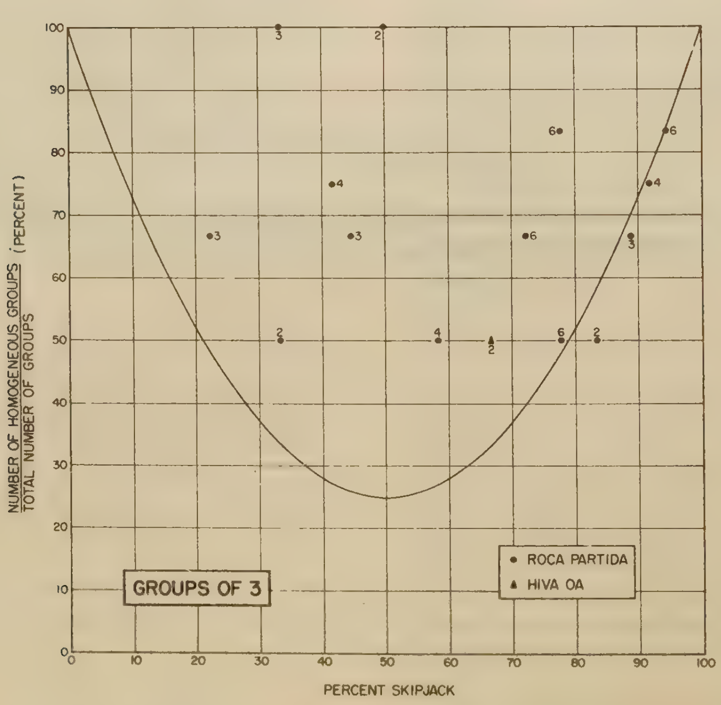

Fig. 3b Comparison of observed percentage of homogeneous groups in species mixtures of different proportions with that expected by chance.

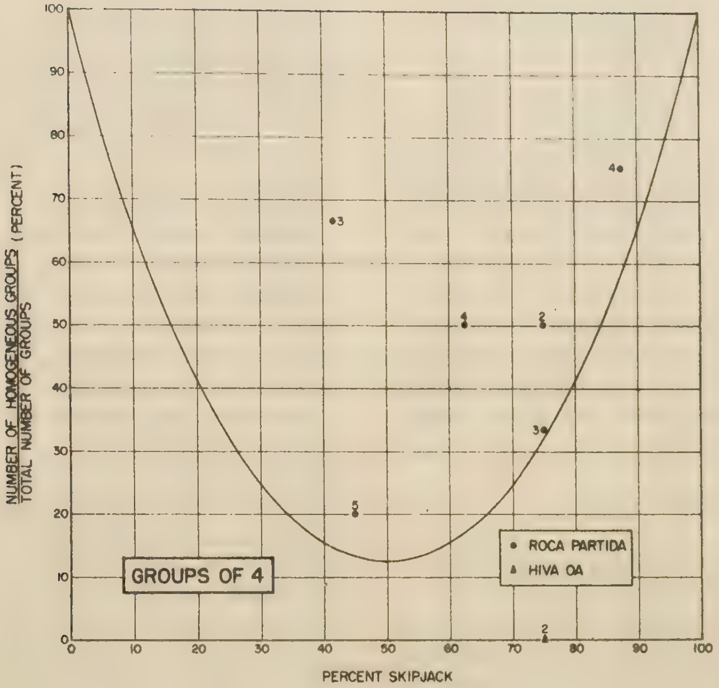

Fig. 3c Comparison of observed percentage of homogeneous groups in species mixtures of different proportions with that expected by chance.

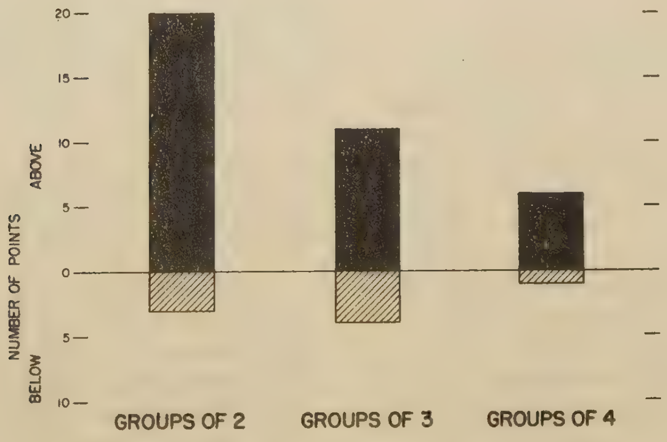

Fig. 4 Distribution of observed percentages of homogeneous groups above and below those expected by chance.

The chi-square value is a conservative one for the following reasons. (1) The expected curves of Fig. 3 are based on the limits of p, which are maximum values of p. Had p been based on numbers of s + y comparable to the observed numbers, more of the points would have fallen above the curves. (2) More than one fish in pursuit of the same prey sometimes followed parallel paths. These fish were not distinguished from those orienting with each other. Including them in the data introduced an error biased towards heterogeneous groups, because fish of the same species pursuing the same prey were more likely to be schooling together before sighting the prey than fish not of the same species pursuing the same prey.

4 CONCLUSION AND DISCUSSION

The results lead to the conclusion that yellowfin and skipjack tuna prefer to school with members of their own species. Occurrences of both species together, therefore, are most likely congregations of separate schools of yellowfin and skipjack responding to some common external stimulus.

It appears most likely that the stimulus which brings schools of yellowfin and skipjack together is a common interest in similar foods. This hypothesis would be strengthened if it could be shown that aggregations of the two species are more frequently actively feeding than are "pure schools" of either species alone. In fact, certain differences between the catches of pole-and-line fishing boats and purse-seiners (Broadhead and Orange, 1960) provide evidence that this is the case. The pole-and-line fishery, which depends on fish in the act of feeding for its effectiveness, takes a higher percentage of its total catch from mixed aggregations than does the purse-seine fishery in which active feeding is not a prerequisite to capture. The hypothesis is further supported by the results of studies for the stomach contents of the two species, for lists of yellowfin food items (Reintjes and King, 1953) and skipjack food items (Yuen, 1959) show many similarities.

The assumption that the coincidental pursuit of the same prey is what brings schools of skipjack and yellowfin together also points to an explanation of the tendency for large skipjack to be found with large yellowfin and small skipjack with small yellowfin in mixed aggregations, a tendency which taken by itself would appear to indicate true interspecific schooling. It has been shown that the diet of yellowfin changes to some extent as the fish grow and become capable of ingesting larger organisms (Reintjes and King, 1953), and the same thing might reasonably be expected to be true of skipjack. Thus, the apparent size association in "mixed schools" may be ascribable to a parallel development of food habits with growth in the two species, such that large yellowfin and large skipjack will tend to converge on the same prey, while small individuals of both species will pursue other, smaller feed. Again, there is evidence to support this idea in the differences between purse-seine and pole-and-line catches. The difference in size of yellowfin taken from monospecific schools and from mixed aggregations is greater in the purse-seine fishery than in the pole-and-line fishery. This indicates that the large yellowfin taken from monospecific schools by purse seines have developed food habits which lessen the likelihood of their converging on a common prey in company with the smaller tuna species.

5 SUMMARY

The schooling behavior of skipjack and yellowfin tuna occurring together was studied by analyzing data on body lengths from 83 composite aggregations of these species and motion picture records of 2 of these aggregations. The results show that :

(1) There is a mean difference of 93 mm between the mean lengths of yellowfin and skipjack found in the same aggregation.

(2) Small yellowfin (460-490 mm mean length) were found with small skipjack (340-450 mm mean length) and larger yellowfin (490-1060 mm mean length) with larger skipjack (470-650 mm mean length), but no interspecific correlation in lengths existed within each group.

(3) Skipjack and yellowfin within an aggregation were not uniformly mixed.

(4) More monospecific groups of schooling individuals were observed than would have been expected if there were no species selection in schooling.

A conclusion was made that skipjack and yellowfin in composite aggregations were from separate specific schools attracted to some common external stimulus. Food was hypothesized as the common stimulus.

6 ACKNOWLEDGMENTS

Thanks are due to: Dr. John Magnuson for enlightening discussions and review of the manuscript, Mr. Reginald Gooding for extracting the data from the films, Mrs. Betty Ann Keala for the advice on mathematical procedures, and Mr. Tamotsu Nakata for the skillfully drawn figures.

Experience Paper No. 26

FOOD OF SKIPJACK IN THE CENTRAL PACIFIC

By

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Abstract

An examination of the stomach contents of 707 skipjack from waters near the Hawaiian, Line, and Phoenix Islands showed that by volume the food consisted of 3.7 percent crustaceans, 19.9 percent molluscs, 74.6 percent fish, and 1.8 percent unidentifiable remains. It was found that skipjack consumed more fish and fewer molluscs than did yellowfin and bigeye tuna. Larval and juvenile tuna, mostly skipjack, constituted a high percentage of the food of skipjack. Smaller volumes of stomach contents were found for: (1) troll as compared with pole-and-line caught skipjack, (2) subsurface as compared with surface caught skipjack, and (3) small as compared with large skipjack. Variation in the detailed composition, but not in the major food groups, was associated with: (1) size of skipjack, (2) distance from land, (3) time of capture, and (4) month of capture. Variation in the proportion of the major food groups utilized was associated with area of capture.

ALIMENTATION DES BONITES A VENTRE RAYE
DU PACIFIQUE CENTRAL

Résumé

L'examen des contenus stomacaux de 707 bonites à ventre rayé provenant des eaux au large de l'archipel des Hawaii et des îles Phoenix et de la Ligne a fourni les pourcentages quantitatifs suivants d'aliments: crustacés, 3,7 pour cent; mollusques, 19,9 pour cent; poissons, 74,6 pour cent; restes non identifiés, 1,8 pour cent. On a constaté que les bonites à ventre rayé consommaient davantage de poissons et moins de mollusques que les thons à nageoires jaunes et les thons obèses. Les stades larvaires et immatures des thons - principalement bonites à ventre rayé - constituent un pourcentage élevé de la

nourriture des bonites à ventre rayé. Le contenu stomacal est moindre dans les cas suivants: 1) bonites à ventre rayé prises à la traîne par rapport à bonites capturées à la canne et à l'hameçon; 2) bonites pêchées en profondeur par rapport à bonites capturées en surface; 3) bonites de petite taille par rapport à bonites de grande taille. Les écarts dans la composition de détail, mais non dans les groupes principaux d'aliments, correspondent aux éléments suivants: 1) taille des bonites; 2) distance de la côte; 3) heure de la capture; 4) mois de la capture. Les variations dans la proportion des principaux groupes d'aliments utilisés sont en rapport avec la zone de pêche.

LA ALIMENTACION DEL BARRILETE EN EL PACIFICO CENTRAL

Extracto

Un examen del contenido estomacal de 707 barriletes procedentes de aguas próximas a Hawaii, las Espóradas Ecuatoriales y las Islas Phoenix, demostró que, en volumen, el alimento estaba formado por el 3, 7 por ciento de crustáceos, 19, 9 por ciento de moluscos, 74, 6 por ciento de peces y 1, 8 por ciento de residuos no identificables. Se observó que el barrilete consumía más peces y menos moluscos que el atún de aleta amarilla y el patudo. Un gran tanto por ciento de la alimentación del barrilete estaba constituido por formas larvales y juveniles, en su mayoría de barrilete. Se hallaron contenidos estomacales inferiores para: (1) el barrilete capturado con curricán en relación con el capturado con liña; (2) el barrilete capturado en la subsuperficie frente al capturado en la superficie, y (3) los individuos de pequeño tamaño en comparación con los de gran tamaño. La variación en la composición detallada, aunque no en los grupos principales de alimentos, se asoció a: (1) el tamaño del barrilete; (2) la distancia de tierra; (3) el tiempo de la captura, y (4) el mes de la captura. La variación de las proporciones de los principales grupos de alimentos utilizados se relacionó con los lugares de captura.

1 INTRODUCTION

The skipjack, Katsuwonus pelamis (Linnaeus), enjoys a wide distribution in the warmer waters of all oceans and forms the basis for commercial fisheries in certain areas. In the Hawaiian Islands, where the skipjack constitutes 50 to 70 percent of the commercial fish catch, production of this species ranged from 6 to 14 million pounds in the years 1948-1960, and it contributed over a million dollars annually to the economy of the Islands (Yamashita, 1958; U. S. Fish and Wildlife Service, 1961).

In Hawaii, as elsewhere in the Pacific, skipjack are taken principally by live-bait, pole-and-line fishing. The catch displays a marked seasonal variation with a major peak in the mid-summer months. The U. S. Bureau of Commercial Fisheries Biological Laboratory at Honolulu is investigating the interrelationships between skipjack and the environment to learn the causes for the seasonal variation and the factors influencing the day-to-day changes in the distribution of the fish on the fishing grounds.

This present study was undertaken for the purpose of examining more specifically variations in the food of skipjack as related to the time, locality, depth, and method of capture. It was hoped that the resulting information would contribute to a better understanding of the general ecology of the skipjack as well as of the annual and seasonal fluctuations in the catch. Comparisons were made of the food of skipjack with that of yellowfin and bigeye tuna.

The food of skipjack is generally well known as the result of the studies of Aikawa (1937), Suyehiro (1938), and Hotta and Ogawa (1955) in Japanese waters, Welsh (1949) in Hawaiian waters, and Ronquillo (1953) in the Philippines. In addition there are numerous scattered references in the literature, particularly in reports e. g., Japan, 1958, on the Japanese skipjack fishery, to various items found in the stomach contents. The statement that the food of skipjack consists of "Crustacea, squid, and fish" is frequently made and, in fact, could be applied to the majority of the tunas.

This is the fifth report of the Honolulu Laboratory dealing with the food of tunas in the central Pacific. The others were concerned with the food of yellowfin (Neothunnus macropterus) (Reintjes and King, 1953), with a comparison of the food of bigeye (Parathunnus sibi) and yellowfin (King and Ikehara, 1956), the food of albacore (Thunnus germo)(Iversen, 1961), and the food of skipjack in Marquesan waters (Nakamura, MS).

Thanks are due the officers and crew members of the Laboratory's research vessels and to all scientific personnel who aided in collecting the stomach samples. Also, special recognition should go to I. Ikehara, T. Otsu, T. Roseberry, A. Y. Shimomura, and D. Yamashita who, at one time or another, assisted in the measurement and identification of the stomach contents.

2 SOURCE OF MATERIALS

This report is based on an analysis of the stomach contents of skipjack collected during the years 1950-56 on 41 cruises (Table I) of the Bureau of Commercial Fisheries' research vessels Hugh M. Smith, John R. Manning, Charles H. Gilbert, and Henry O'Malley, and of the chartered vessels Cavalieri and Commonwealth. The collections were obtained from areas adjacent to the Hawaiian Islands, the Line Islands, and the Phoenix Islands, and from the intervening waters of the central Pacific (Fig. 1).

Of the 4,690 skipjack caught on these cruises, the stomachs of 707, or 15.1 percent, were preserved for subsequent analysis. Of this total, 587 stomachs were obtained from fish captured on or near the surface (25 by purse seining, 66 by surface trolling, and 496 by live-bait fishing), and 120 stomachs were from fish captured on longlines[1/] fishing at depths from 150 to 500 feet. The sampled fish ranged in size from 33 to 88 cm. (1-1/2 to 38 pounds).

3 METHODS

The stomach was removed from the fish at time of capture, placed in a cloth bag, and preserved in 10 percent formalin.

In the laboratory the stomach was slit open and the contents removed, sorted, and identified to the most precise degree practicable. Enumeration and volumetric measurement of each species or group of food organisms were subsequently made and recorded. Material identifiable as parasites, and baits used in the capture of the

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[1/] A description of the Laboratory's longline gear is provided by Mann (1955).

Table I

Skipjack catch and stomach collections by vessel, cruise, cruise period, and fishing method

Vessel	Cruise No.	Cruise period	Fishing method	Number captured	Number examined	Percent examined
Hugh M. Smith	2	Jan.-Feb., 1950	Trolling	10	9	90
			Pole-and-line	10	6	60
	4	May-June, 1950	Pole-and-line	150	54	36
	5	July, 1950	Trolling	2	2	100
	6	August, 1950	Trolling	2	2	100
	7	Oct.-Nov., 1950	Trolling	3	2	67
			Longline	5	4	80
	8	January, 1951	Trolling	1	1	100
	9	June, 1951	Pole-and-line	28	2	7
			Trolling	2	2	100
	11	September, 1951	Longline	23	16	70
	15	May-June, 1952	Trolling	3	3	100
	18	Oct.-Nov., 1952	Longline	14	6	43
	22	September, 1953	Pole-and-line	276	60	22
	26	May-June, 1954	Pole-and-line	159	30	19
			Trolling	3	3	100
	28	Mar.-April, 1955	Pole-and-line	122	12	10
			Trolling	3	3	100
	29	June, 1955	Longline	1	1	100
	31	November, 1955	Trolling	2	1	50
John R. Manning	2	April-May, 1950	Trolling	20	16	80
	3	September, 1950	Trolling	1	1	100
	4	November, 1950	Trolling	6	5	83
	7B-C	Aug.-Sept., 1951	Purse seine	516	25	5
	11	Feb.-Mar., 1952	Longline	17	6	35
	13	November, 1952	Longline	26	2	8
	14	Feb.-Mar., 1953	Longline	30	15	50
	15	May, 1953	Longline	15	6	40
	16	August, 1953	Longline	15	10	67
	18	December, 1953	Longline	6	5	83
	19	January, 1954	Longline	4	4	100
	20	June, 1954	Longline	9	9	100
	28	June, 1955	Longline	3	3	100
			Trolling	1	1	100
	29	Jan.-Feb., 1956	Longline	7	2	29
			Trolling	6	1	17
Henry O'Malley	3	May, 1950	Pole-and-line	18	4	22
	4	July, 1950	Trolling	7	3	43
			Pole-and-line	9	5	56
Cavalieri	1	Aug.-Sept., 1950	Longline	29	14	48
Charles H. Gilbert	7	February, 1953	Trolling	2	2	100
	12	May, 1953	Pole-and-line	35	5	14
	15	Mar.-April, 1954	Longline	18	7	39
	16	July-Aug., 1954	Pole-and-line	591	63	11
			Trolling	1	1	100
	19	February, 1955	Pole-and-line	1	1	100
			Trolling	16	2	12

Table I (con.)

Skipjack catch and stomach collections
by vessel, cruise, cruise period, and fishing method

Vessel	Cruise No.	Cruise period	Fishing method	Number captured	Number examined	Percent examined
Charles H. Gilbert-(con.)	21	May-June-Jul., 1955	Pole-and-line	986	99	10
		Jul.-Aug., 1955	Pole-and-line	1460	155	11
			Trolling	1	1	100
	23	Sept.-Oct., 1955	Trolling	5	5	100
			Longline	1	1	100
	25	Jan.-Feb., 1956	Longline	5	5	100
Commonwealth	4	July, 1955	Longline	4	4	100
TOTAL				4690	707	Avg. 15.1

fish were omitted from the final analysis. In many instances the stomachs contained small amounts of unidentifiable, amorphous material which was listed as "unidentified remains." This material has been included in the final analysis, but it is relatively small in volume and should not distort the results.

The methods and literature used in the identification of the food organisms were essentially the same as those employed by Reintjes and King (1953) and will not be reviewed here. Berg's (1947) system of classification and nomenclature was used for the family names of the forage fishes, except where other names appeared to be more acceptable.

Three basic criteria were used to assess the importance of the various food items; these were the number of such organisms, their volume, and their frequency of occurrence, indicating, respectively, their general abundance, relative food value, and availability. Appendix Table I contains a list of all the food organisms found in the skipjack stomachs. For each food element there is indicated the total number of each item, the number of stomachs in which it was found, its percentage of occurrence, the total volume of each item, and its percentage of the total aggregate volume.

Because of the great variability in the data, and for other reasons explained by King and Ikehara (1956), no attempt has been made to apply statistical tests. The conclusions, therefore, are based on average values with no appraisal of their statistical significance. Sampling has been extensive, however, and it is not likely that the conclusions would be greatly modified by further observations.

When a general index of importance was needed, e.g. in evaluating the importance of different fish families, the items were ranked in descending order of total number, frequency of occurrence, and volume. These ranks were then summed and an overall rank for each item obtained.

4 RESULTS

It is difficult to make proper comparisons of the foods of skipjack, yellowfin, and bigeye tunas since the specimens of these fishes from which stomach samples were obtained differ greatly in size and have somewhat different vertical and horizontal distributions (Brock, 1949; Nakamura, 1949; Murphy and Shomura, 1953a, 1953b). Skipjack, with a maximum size of about 50 pounds, are taken principally on the surface and are found in coastal and oceanic waters; yellowfin reach a maximum of about 200 pounds and are taken from inshore and open ocean areas; bigeye reach a maximum of about 300 pounds, are usually taken well below the surface on longline, and are strictly oceanic. Differences in the food of yellowfin and bigeye, as related to the depth and distance of capture from land, have been discussed previously (Reintjes and King, 1953; King and Ikehara, 1956).

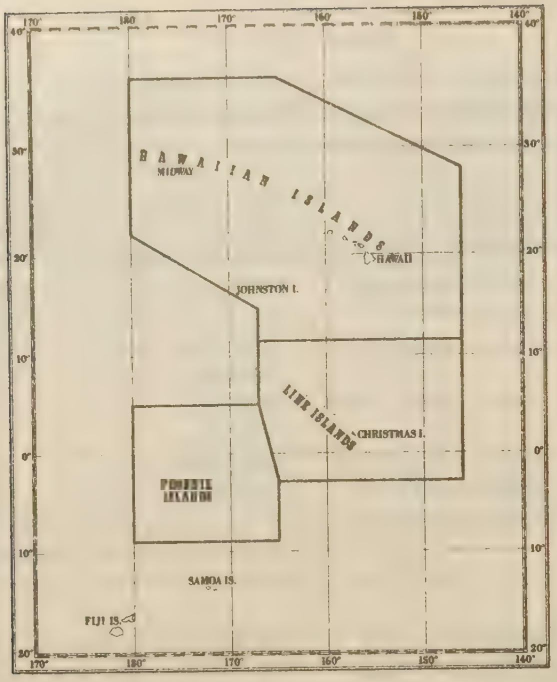
170°
180
170°
160°
150°
140°
40°
30°
20°
10°
0°
10°
20°
HAWAIIAN ISLANDS
MIDWAY
HAWAII
JOHNSTON I.
LINE ISLANDS
CHRISTMAS I.
PHOENIX ISLANDS
SAMOA IS.
FIJI IS.

Fig. 1 Area of the central Pacific from which the skipjack stomach collections were obtained.

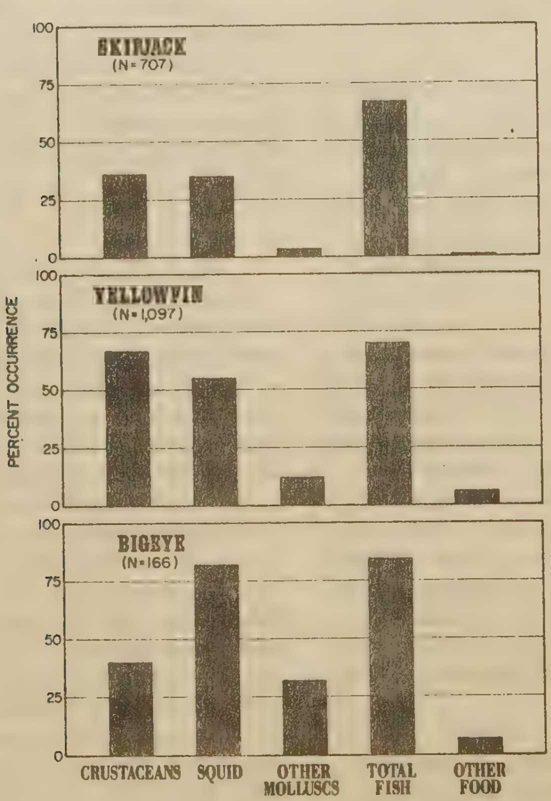

Fig. 2 Percentage frequency of occurrence of the major groups of food organisms for skipjack, yellowfin, and bigeye tuna.

The food of skipjack includes a wide variety of organisms representing 11 invertebrate orders and 42 fish families (Appendix Table I). In respect to the consumption of the major food categories, fish occurred in 67 percent of the stomachs, Crustacea in 36 percent, and squid in 35 percent (Fig. 2). Those fish families ranking highest in frequency of occurrence were Gempylidae, Scombridae, Mullidae, Chaetodontidae, and Holocentridae (Table II). The first two of these families are fishes of the open ocean, while the last three families are primarily fishes of the reef, lagoon, and other coastal waters. However, a considerable proportion of the members of these three families were larval and juvenile forms often found in an oceanic environment some distance from shore. The reef-frequenting habit of the yellowfin is demonstrated by the high occurrence in its diet of Crustacea (such as stomatopods and crab larvae) and reef-dwelling fishes of the families Acanthuridae and Balistidae (Reintjes and King, 1953). The more oceanic Bramidae are also common, however. The food of bigeye (King and Ikehara, 1956) is characterized by the high occurrence of such oceanic fishes as the Gempylidae, Bramidae, and Paralepidae. Squid are prominent in the food of all three of the tunas.

Table II

Variation in the volume and composition
of the stomach contents
of skipjack, yellowfin, and bigeye tuna

	Average vol. (cc.) per stomach			Percentage of occurrence			Percentage of total volume		
	Skip-jack	Yellow-fin1/	Bigeye2/	Skip-jack	Yellow-fin	Bigeye	Skip-jack	Yellow-fin	Bigeye
Crustaceans	.7	11.8	2.3	36.1	66.9	40.4	3.7	24.8	1.7
Molluscs (total)	3.9	13.3	48.2	36.4	-	-	19.9	27.9	35.9
Squids	3.9	12.5	44.0	34.7	55.4	82.5	19.5	26.2	32.8
Other molluscs	.1	.8	4.1	3.4	-	-	.4	1.7	3.1
Fish	14.7	22.3	83.7	67.0	70.4	84.3	74.6	46.7	62.3
Paralepidae	-	-	2.6	.1	.1	10.2	.1	-	2.9
Holocentridae	5.6	-	.1	4.9	.1	.6	1.4	-	-
Carangidae	1.0	5.3	.1	4.4	2.2	.6	5.2	11.1	-
Bramidae	.1	1.9	29.7	2.0	13.8	15.7	.7	4.1	17.2
Mullidae	1.0	-	-	8.2	-	.6	5.1	-	-
Acanthuridae	.1	.9	-	4.8	16.8	-	.5	1.9	-
Gempylidae	.6	.5	15.0	12.3	4.5	25.9	3.2	1.0	11.2
Nomeidae	.7	-	1.1	3.6	.1	13.2	3.6	-	.7
Scombridae	4.9	4.4	5.4	10.6	2.2	1.2	25.0	9.3	4.0
Chaetodontidae	.2	-	-	6.9	1.2	-	1.0	0.1	-
Balistidae	-	1.2	-	.1	8.3	-	-	2.4	-
Molidae	.7	.5	1.6	3.8	.1	1.6	3.5	1.0	1.2
Other foods	.4	.3	-	5.2	6.3	6.0	1.8	.6	-
All foods	19.7	47.7	134.3	88.4	90.8	95.2	-	-	-
Number of stomachs examined	707	1097	166						
Number of stomachs empty	82	101	8						
Average fork length (cm.)	59.7	105.1	145.6						
Average weight (lbs.)	10.5	49.8	141.8						
Average volume (cc.) food per pound of body weight	1.9	1.0	.9						

1/ Data from Reintjes and King, 1953

2/ Data from King and Ikehara, 1956

With respect to volume, fish composed 75 percent of the food of skipjack, squid 20 percent, and Crustacea 4 percent (Fig. 3). The most important fish families, in order of importance, were Scombridae, Carangidae, Mullidae, Nomeidae, and Molidae (Table II). The second and third of these fish families are generally more abundant in coastal waters and near shore habitats; the first and the last two are characteristic of the open ocean. For the yellowfin, Crustacea were large in bulk, and the dominant fish families were Carangidae, Scombridae, and Bramidae; in the bigeye, Crustacea were very low in bulk, and Bramidae, Gempylidae, and Scombridae were important in that order. Matsumoto (1958) has shown that, in plankton hauls made at different depths in the central Pacific, the greatest numbers of tuna larvae were obtained in the upper 50 meters. It is interesting to note that larval and juvenile tunas compose a higher percentage of the food of the more surface-dwelling skipjack and yellowfin than of the deeper-dwelling bigeye.

4.1 Variation in food with size of skipjack

There were two principal size groups, with modes at 45 cm and 72 cm, represented in the 646 skipjack from which stomachs were collected and the fork length recorded (Fig. 4). Secondary modes were evident at 53 cm and at 78-80 cm. For Hawaiian skipjack, Brock (1954) found modal lengths of 42-45 cm, 68-73 cm, and 79-80 cm, which were interpreted as most likely to represent ages 1, 2 and 3 years respectively. Our 45-cm mode corresponds, therefore, to Brock's year 1 class, the 72-cm mode to his year 2 class, and the secondary mode at 78-80 cm to his year 3 class.

To examine differences in the food related to body size of the skipjack, we split our sample into two size groups: (1) fish less than 60 cm in fork length (about 10 lbs), and (2) fish 60 cm and over. The group of smaller fish (355) averaged 46.4 cm (4.5 lbs), whereas the group of larger fish (291) averaged 74.5 cm (22 lbs).

The average volume of food per stomach was 15.5 cc for skipjack less than 60 cm and 27.4 cc for those 60 cm and over. This is in good agreement with Yuen (1959), who noted that volume of stomach contents of skipjack of < 50 cm, 50-60 cm and > 60 cm was 9.1 ml, 20.4 ml, and 35.6 ml respectively. No important difference was noted between the two size groups in respect to the percentage of occurrence or percentage by volume of the major food categories (Fig. 5). However, Yuen (1959) noted an increase in consumption of fish with an increase in the length of skipjack. A detailed survey of the data shows, however, that with an increase in body size the feeding shifted from crab larvae to the more pelagic amphipods and euphausiids and from juvenile carangids and mullids to scombrids and nomeids (Table III), the latter fishes being the more oceanic in their distribution. These variations in composition within the major food categories and the increase in average volume of stomach contents appeared to be the principal differences associated with the increase in body size.

4.2 Variation in food with method of capture

Because of the incompleteness of our sampling any differences in the food related to the method of capture of the skipjack are difficult to isolate from differences associated with locality and depth of capture. Skipjack were caught by pole-and-line, surface trolling, purse seine, and longline fishing. In the first three methods the fish were taken on, or near, the surface, and in the latter method they may have been captured well below the surface at depths from 150 to 500 feet. Unfortunately, over 70 percent of our samples from the longline or subsurface-caught fish were from the Line Islands area, whereas over 90 percent of the samples of surface-caught fish were from Hawaiian waters. Also, we should point out that only a small number of stomachs were examined from purse-seine-caught fish, and these came from just two schools. Because of these limitations of the data we shall restrict our conclusions to very generalized remarks.

In respect to variations in the general food categories, crustaceans were small in volume but moderate in number and frequency of occurrence in all three groups of surface-caught skipjack (Fig. 6). Molluscs (principally squids) were low in volume and in number in the pole-and-line and purse-seine-caught fish but were of much greater importance in the troll-caught skipjack. Fish were an important food item in all three groups, but among the troll-caught skipjack they appeared to be replaced to some extent by molluscs.

Among the fish families represented in the food, we find that Scombridae, Carangidae, Mullidae, and Gempylidae were important in the food of the pole-and-line-caught skipjack, as compared with Scombridae and Kuhliidae for the purse-seine-caught fish and Gempylidae and

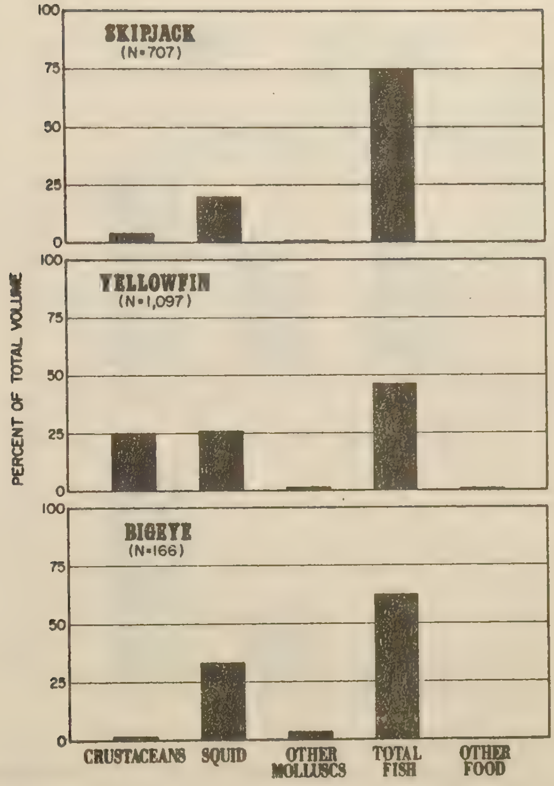

Fig. 3 Percentage of total aggregate volume of the major groups of food organisms for skipjack, yellowfin, and bigeye tuna.

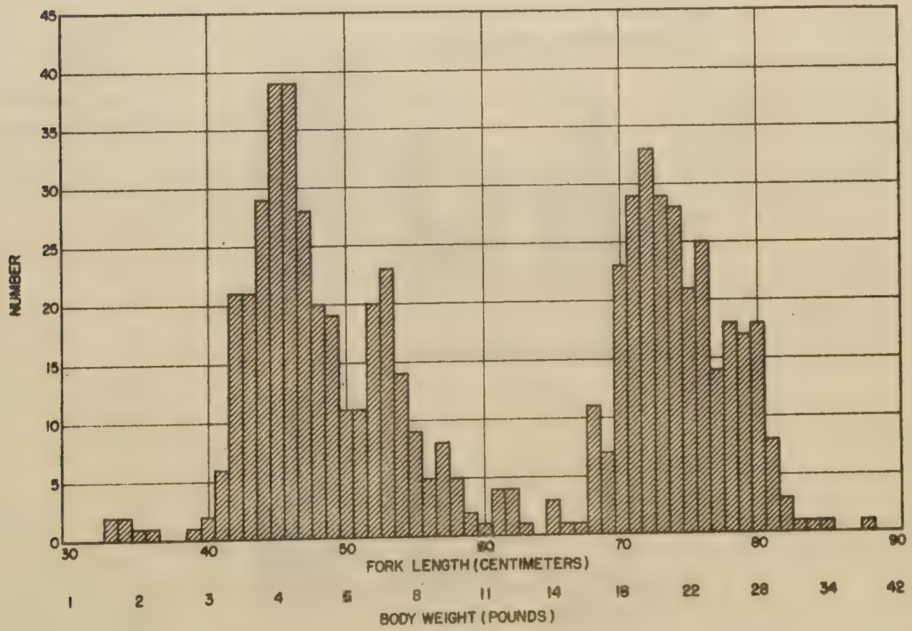

Fig. 4 Length-frequency distribution of 646 skipjack from which stomachs were collected and the fork length recorded.

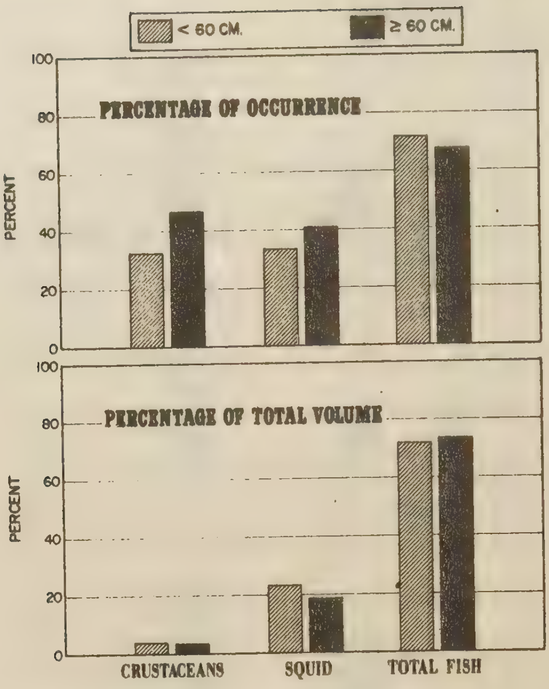

Fig. 5 Percentage of occurrence and percentage of aggregate total volume of the major food elements for skipjack of two size groups, less than 60 cm. and 60 cm. and over in fork length.

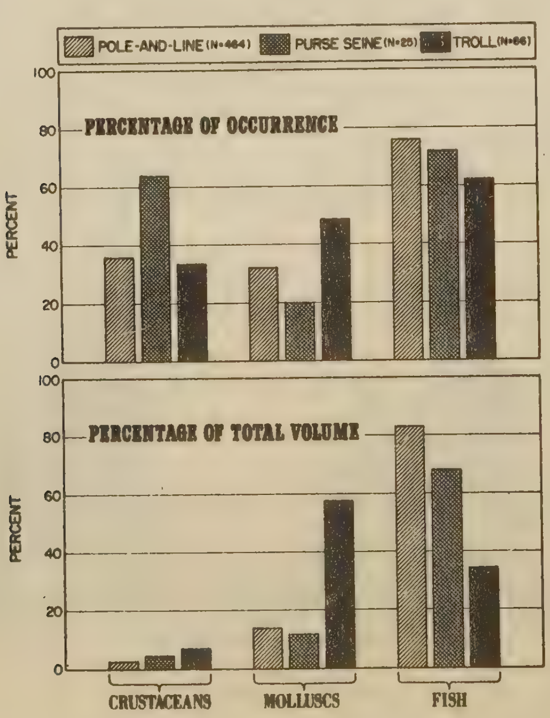

Fig. 6 Variation in the volume and composition of the major categories of the food of surface-caught skipjack as related to method of capture.

Table III

Variation in the food of skipjack
of less than 60 cm. and of
60 cm and over fork length

Food organisms	Average volume(cc.) per stomach		Percentage of occurrence		Percentage of total volume	
	< 60 cm Fork length	> 60 cm Fork length	< 60 cm Fork length	> 60 cm Fork length	< 60 cm Fork length	> 60 cm Fork length
Crustaceans	.6	1.0	32.7	46.7	4.0	3.7
Molluscs (total)	3.7	5.3	34.6	41.9	23.6	19.3
Squids	3.6	5.2	33.5	40.6	23.2	18.9
Other molluscs	.1	-	1.1	6.2	.4	.5
Fish (total)	11.2	20.2	71.8	67.7	71.9	73.7
Carangidae	1.3	.5	7.0	2.1	8.2	.2
Mullidae	1.6	.4	13.5	3.1	10.4	1.4
Gempylidae	.8	.5	16.9	10.7	5.3	1.9
Scombridae	2.1	10.2	15.2	9.3	13.4	37.3
Nomeidae	.2	1.1	2.5	3.4	1.3	4.1
Other foods	.1	.9	2.3	9.6	.4	3.3
All foods	15.5	27.4	85.9	87.3		
Number of stomachs examined	355	291				
Number of stomachs empty	50	37				
Average fork length (cm.)	46.4	74.5				
Average weight (lbs.)	4.5	22.0				
Average volume (cc.) food per pound of body weight	3.4	1.2				

Myctophidae for the troll-caught skipjack (Table IV). The most marked difference among these three groups of skipjack, however, was the very low average volume (9.9 cc) and high percentage of empty stomachs (15 percent) found in the troll-caught fish. This difference is obvious to observers in the field and has also been reported by Welsh (1949). Perhaps surface trolling more than the other fishing methods is selective of fish with near-empty stomachs; or as suggested by Welsh (1949) there may be a higher degree of regurgitation among the troll-caught fish. This difference in volume of stomach contents was not found for troll- and pole-and-line caught yellowfin (Reintjes and King, 1953).

If we compare the volumes and composition of the food of the surface-caught skipjack with those of the subsurface (longline)-caught skipjack, all taken 25 miles or more from land, we find no marked differences in respect to the major categories, although molluscs and crustaceans ranked larger in volume in the subsurface- than in the surface-caught skipjack, whereas fish were just the reverse (Fig. 7).

The fish families most prominent in the stomachs of surface-caught skipjack were Scombridae, Carangidae, Exocoetidae and Molidae, as compared with Gempylidae, Sternoptychidae, and Myctophidae in the subsurface catches (Table V). These occurrences in the food agree generally with what is known of the distribution of these fishes.

The subsurface skipjack (74.2 cm) averaged larger than the surface-caught fish (64.2 cm) but contained only about 1/3 as much food in their stomachs (15.66 cc and 43.7 cc, respectively).

4.3 Variation in food with distance from land

In order to examine differences in the food related to the distance of the nearest land from the point of capture of the skipjack, an arbitrary scale of 0-9, 10-24, 25-49, 50-99, 100-199, and 200+ miles was used.

Although the data are few, in Hawaiian waters among the surface-caught skipjack, the average volume of stomach contents increased in an offshore direction out to 50 miles from land and then varied irregularly at further distances offshore (Fig. 8). The samples from 100-199 miles had the lowest average volumes.

The trend described above is largely due to the variation in the volume of fishes, which were the dominant element in the food. Although crustaceans varied irregularly with distance from land, they were most prominent at the 50-99 miles category (Table VI). Molluscs also varied irregularly but were of greatest significance in the 10-24 miles category.

Among the various fish families represented, Scombridae, Gempylidae, and Exocoetidae were important in the offshore category of 100-199 miles. Scombridae were also the most important item in the diet of skipjack taken between 25 and 49 miles offshore, followed by Carangidae, Gempylidae, and Holocentridae. Important fish families in the diet of skipjack taken between shore and 9 miles were Scombridae, Mullidae, and Carangidae. With respect to size, the skipjack sampled in the offshore waters were larger than those of the inshore waters.

4.4 Variations related to areas of capture

For an analysis of variations related to area of capture, our data include 506 samples from the Hawaiian area, 92 from the Line Islands area, and 30 from the Phoenix Island area. Results, in terms of frequency of occurrence and volumetric percentages of the major groups of food organisms (Table VII) suggest the following: (1) Skipjack from the Hawaiian area depended on fishes to a greater extent than those from the Phoenix or Line Islands; (2) skipjack from the Phoenix Island area utilized molluscs, crustaceans, and fishes equally as sources of food, and (3) skipjack from the Line Islands area depended on fishes to a lesser degree than those from the other two areas and to a greater extent on squids and crustaceans.

Rather wide differences are found when comparing the diet of skipjack in the central Pacific area with that of skipjack from other areas of the Pacific. Schaefer (1960) noted that in the eastern Pacific the diet included a much greater volume of Crustacea (62.4 percent) than in the central Pacific (3.7 percent), while the fish and molluscan portions of the diet of eastern Pacific skipjack constituted 4.0 percent and 33.4 percent by volume respectively. The crustacean portion of eastern Pacific skipjack food consisted almost entirely of euphausiids, 57.6 percent, and red crabs (Pleuroncodes), 3.8 percent.

Table IV

Variation in the volume and composition of the food of surface-caught skipjack in relation to three methods of capture: pole-and-line, purse seine, and surface trolling

Food organisms	Average volume (cc) per stomach			Percentage of occurrence			Percentage of total volume		
	Pole-and-line	Purse seine	Surface troll	Pole-and-line	Purse seine	Surface troll	Pole-and-line	Purse seine	Surface troll
Crustaceans	.7	1.6	.7	36.0	64.0	33.3	2.7	4.6	7.1
Molluscs (total)	3.3	4.2	5.7	32.1	20.0	48.5	13.9	11.8	57.7
Squids	3.3	4.2	5.4	31.7	20.0	45.5	13.9	11.8	54.7
Other molluscs	-	-	.3	1.3	-	7.6	.1	-	3.0
Fish (total)	19.9	24.0	3.4	75.9	72.0	62.1	83.1	68.1	34.2
Myctophidae	-	-	.5	-	-	3.0	-	-	5.3
Holocentridae	.4	-	-	7.8	-	-	1.8	-	-
Kuhliidae	-	2.5	-	-	4.0	-	-	7.2	-
Carangidae	1.5	-	-	6.7	-	-	6.4	-	-
Bramidae	.2	-	.1	1.7	-	4.5	.7	-	.8
Mullidae	1.4	-	-	11.0	4.0	-	5.7	-	-
Gempylidae	1.0	-	.6	14.2	-	10.6	4.1	-	5.7
Scombridae	7.9	5.4	.1	16.8	20.0	3.0	32.9	15.4	.9
Nomeidae	.9	-	-	3.7	-	-	4.0	-	-
Other foods	.1	5.4	.1	1.7	48.0	4.6	.2	15.4	1.0
All foods	23.9	35.2	9.9	87.1	96.0	84.8			
Number of stomachs examined	464	25	66						
Number of stomachs empty	60	1	10						
Average fork length (cm.)	50.5	64.2	60.9						
Average weight (lbs)	6.0	13.4	11.2						
Average volume (cc) food per pound of body weight	4.0	2.6	0.9						

Table V

Variation in the volume and composition
of the food of surface- and subsurface-caught skipjack
taken 25 or more miles from land

Food organisms	Average volume (cc) per stomach		Percentage of occurrence		Percentage of total volume	
	Surface	Sub-surface (longline)	Surface	Sub-surface (longline)	Surface	Sub-surface (longline)
Crustaceans	1.1	.9	57.0	42.3	2.5	5.8
Molluscs (total)	3.6	9.2	78.5	72.2	8.2	59.3
Squids	3.5	9.0	78.5	67.0	8.1	57.7
Other molluscs	.1	.3	2.5	10.3	.1	1.6
Fish (total)	39.0	5.2	80.2	51.5	89.3	33.6
Sternoptychidae	-	1.1	-	4.1	-	6.9
Myctophidae	-	.4	-	2.1	-	2.3
Exocoetidae	1.2	-	7.4	-	2.7	-
Carangidae	1.9	-	2.5	-	4.3	-
Gempylidae	.5	.4	9.1	13.4	1.1	2.6
Scombridae	21.5	.3	12.4	4.1	49.2	1.7
Molidae	1.6	-	4.1	-	3.7	-
Other foods	-	.2	1.7	6.2	.1	1.3
All foods	43.7	15.6	81.8	91.8		
Number of stomachs examined	121	97				
Number of stomachs empty	22	8				
Average fork length (cm)	64.2	74.2				
Average weight	13.4	21.7				
Average volume (cc) food per pound body weight	3.3	.7				

Table VI

Variation in the volume and composition of stomach contents of surface-caught skipjack from Hawaiian waters in relation to distance from land

	Average volume (cc) per stomach						Percentage of occurrence						Percentage of total volume					
	0[1] to 9	10 to 24	25 to 49	50 to 99	100 to 199	200+	0 to 9	10 to 24	25 to 49	50 to 99	100 to 199	200+	0 to 9	10 to 24	25 to 49	50 to 99	100 to 199	200+
Crustaceans	.5	.7	.6	1.4	.2	1.2	28.4	45.3	33.1	44.2	25.8	41.4	4.3	3.3	1.4	5.3	1.6	4.5
Molluscs (total)	2.0	5.2	.8	3.6	.8	2.0	27.0	34.4	70.3	26.9	19.4	48.3	16.1	24.6	2.1	13.6	8.8	7.2
Squids	2.0	5.2	.8	3.6	.7	2.0	25.0	33.6	70.3	26.9	16.1	44.8	16.0	24.5	2.1	13.6	8.1	7.2
Other molluscs	-	-	-	-	.1	-	2.0	.8	-	-	3.2	3.5	.1	.2	-	-	.7	-
Fish (total)	10.0	15.3	37.0	21.6	8.2	24.7	68.2	80.5	83.9	76.9	77.4	82.8	79.6	72.1	96.4	81.1	89.6	88.4
Synodontidae	.3	-	-	-	-	-	12.2	3.1	.8	-	-	-	2.4	.2	-	-	-	-
Exocoetidae	-	-	.5	.9	.6	1.1	.7	-	2.5	3.8	6.5	13.8	.2	-	1.4	3.6	6.2	4.0
Holocentridae	.7	.2	.6	-	-	-	11.5	5.5	11.9	1.9	-	-	5.7	1.3	1.5	-	-	-
Carangidae	1.1	1.2	2.8	1.7	-	-	6.8	7.8	9.3	1.9	-	-	8.5	7.5	7.3	6.5	-	-
Mullidae	1.1	3.1	.5	.3	-	-	12.2	21.9	5.9	5.8	-	-	9.0	20.4	1.4	1.2	-	-
Chaetodontidae	.1	.3	.2	1.0	-	-	9.5	11.7	9.3	15.4	-	-	1.1	2.2	.4	3.8	-	-
Gempylidae	.2	1.1	1.0	.9	1.3	.4	10.1	15.6	13.6	17.3	16.1	13.8	1.7	7.3	2.5	3.3	14.4	1.6
Scombridae	1.7	2.4	24.9	1.7	2.0	-	15.5	24.2	18.6	5.8	12.9	-	13.5	15.4	64.9	6.3	21.8	-
Molidae	.9	.6	.2	3.9	-	6.0	4.7	3.1	2.5	17.3	-	17.2	6.9	3.9	.1	14.8	-	21.5
Other foods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All foods	12.5	21.2	38.4	26.6	9.2	27.9	83.1	96.9	88.1	84.6	90.3	85.7						
Number of stomachs examined	148	128	118	52	31	29												
Number of stomachs empty	25	4	14	8	3	5												
Average fork length (cm.)	47.1	54.3	54.1	64.2	63.4	70.3												
Average weight (lbs)	4.7	7.7	7.6	13.4	12.8	18.1												
Average volume (cc) food per pound of body weight	2.7	2.8	5.0	2.0	.7	1.5												

[1] Distance from land, in miles.

Table VII

Variation in the volume and composition of the stomach contents of skipjack in relation to area of capture

Food organisms	Average volume (cc) per stomach			Percentage of occurrence			Percentage of total volume		
	Hawaiian Is.	Line Is.	Phoenix Is.	Hawaiian Is.	Line Is.	Phoenix Is.	Hawaiian Is.	Line Is.	Phoenix Is.
Crustaceans	.7	1.0	.5	36.0	41.3	43.3	3.0	8.4	4.0
Molluscs (total)	2.6	8.5	3.4	29.7	58.7	60.0	11.5	70.4	26.2
Squids	2.6	8.4	3.1	29.1	57.6	46.7	11.4	69.4	24.2
Other molluscs	-	.1	.3	1.2	5.4	26.7	.1	1.0	2.1
Fish (total)	19.5	2.5	9.0	77.3	51.1	63.3	85.5	20.7	68.9
Sternoptychidae	-	.7	1.0	.6	1.1	6.7	.1	5.9	8.2
Myctophidae	.2	.4	-	.6	2.2	-	.9	3.2	-
Carangidae	1.4	-	-	5.9	-	-	6.2	-	-
Bramidae	-	-	-	-	3.3	-	-	.2	-
Mullidae	1.4	-	-	10.7	1.1	-	6.0	.3	-
Gempylidae	.7	.4	.8	12.3	13.0	13.3	3.2	3.8	5.9
Scombridae	7.2	-	4.8	16.6	1.1	10.0	31.6	.3	36.8
Nomeidae	1.0	.1	-	4.0	5.4	-	4.3	.7	-
Other foods	-	-	.1	-	2.2	6.7	-	.4	.9
All foods	22.8	12.0	13.0	88.5	84.8	86.7			
Number of stomachs examined	506	92	30						
Number of stomachs empty	58	14	4						
Average fork length (cm)	56.0	69.7	66.9						
Average weight (lbs)	8.5	17.7	15.4						
Average volume (cc) food per pound of body weight	2.7	.7	.8						

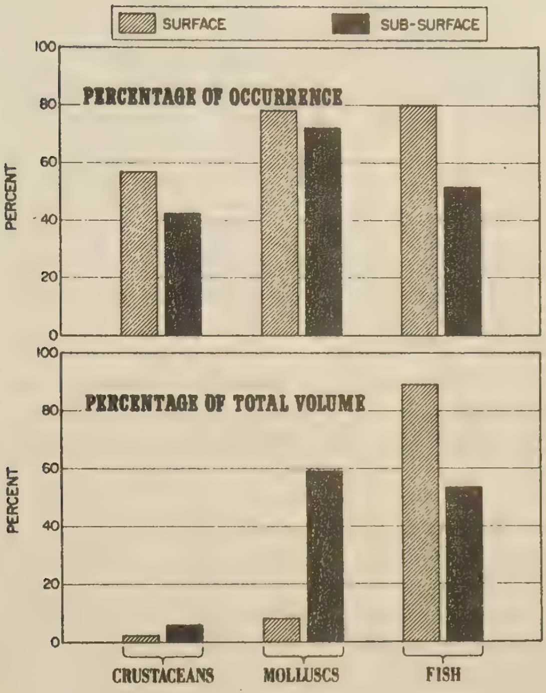

Fig. 7 Variation in the volume and composition of the food of surface-caught (pole-and-line, purse-seine, and troll) and of subsurface-caught (longline) skipjack.

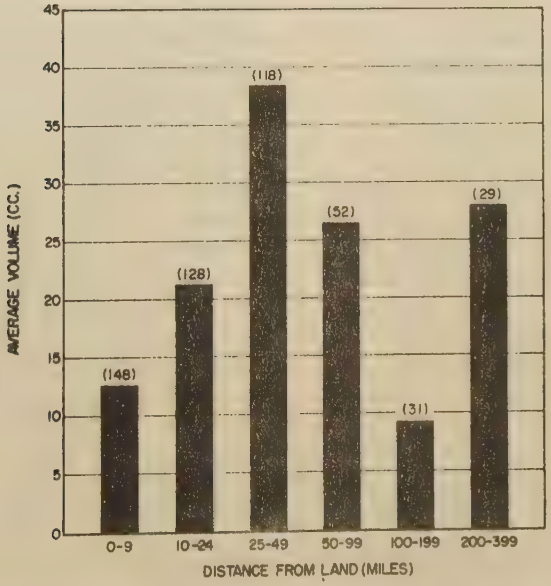

Fig. 8 Variations in the average volume of stomach contents of surface-caught skipjack from Hawaiian waters in relation to distance from land. Figures in parentheses show number of skipjack in sample.

Nakamura (MS) found that Crustacea occurred more frequently in the stomachs of skipjack caught in the waters of French Oceania, 72.3 percent, as compared to skipjack caught in Hawaiian waters, 36.1 percent. The occurrence of molluscs and fish in the stomachs of skipjack from French Oceania was not greatly different from that for Hawaiian waters.

4.5 Variations related to time of capture

To examine differences related to time of capture, samples were grouped according to hour of capture, and further summarized into four arbitrary time periods, viz., dawn to 0859, 0900 to 1159, 1200 to 1459, and 1500 to dark. Only samples taken within 9 miles of the shores of the Hawaiian Islands were numerous enough to be used in this analysis.

The results summarized in Table VIII and Fig. 9 suggest that skipjack have a peak feeding period between 0700 and 0900, possibly due to intensified foraging or to a higher availability of forage at this time. Following this peak at 0900 there was a gradual decline in feeding (or availability of food) until 1300. The time between 1300 and 1600 appeared to be a period of little feeding activity, indicated by the lowest volume of stomach contents for the day, followed by a sharp increase in feeding during the late afternoon. Throughout the day fish were the predominant item in the diet, as judged by frequency of occurrence and volume, followed by molluscs, mainly squids, and then by crustaceans.

It is interesting to note that, in this area at least, some of the major food fishes did not appear in stomach contents at all times of day. Table VIII shows that scombrids, carangids, gempylids, acanthurids and molids were not found in stomachs of fish caught before 0900, and in fact, carangids did not appear in any significant quantities until after noon. Mullids, holocentrids, chaetodontids, acanthurids, and molids were not consumed between 1200 and 1500. It seems likely that the sporadic appearance of certain forage organisms in skipjack stomachs reflects not a selective feeding, but rather changes in availability of the different food organisms.

Many of the forage organisms are believed to inhabit deeper water during daylight hours, rising to the surface at night, e.g., squids, myctophids, sternoptychids. Some, such as sternoptychids, apparently move below the vertical range of skipjack during the day and are consumed only during early morning hours. Others, such as squids and myctophids, remain available to skipjack during daylight hours, and, in fact, squid form about one-fifth of the food of skipjack caught at all times except the 0900 to 1159 period. This might indicate either (1) a slight preference for squid, sufficient to stimulate an active search, or (2) that the vertical range of the squid and skipjack are very close together and overlap to a certain extent. Since the stomachs of longline-caught skipjack contained more squid than did stomachs of surface-caught skipjack, it is likely that the latter situation pertained.

As no samples were collected during the 12 hours between dusk and dawn, it is not possible to state whether or not skipjack feed at night. Welsh (1949) mentioned the rapid rate of digestion for skipjack, and Nakamura (MS) has found that skipjack confined in a pond pass food (frozen shrimp) through their entire digestive tract in less than 1½ hours. Nakamura further states that pond-held skipjack would not feed at night when the only illumination was a single 150-watt light. This evidence indicates that, if no appreciable feeding takes place after dark, the stomachs of skipjack caught in the early morning should be either (1) empty or (2) contain relatively undigested food. Although the results were generally found to be so, the high incidence of squid in late stages of digestion suggests that feeding occurs at or immediately before dawn.

4.6 Seasonal variation

As with the variations by time, only the samples collected within 9 miles of the Hawaiian Islands were numerous enough to permit examination of differences due to seasonal variations in diet. Further, the majority of samples were collected during the summer months so that comparisons for all seasons of the year were not possible. However, certain points of interest emerged when the contents of stomachs sampled in 5 consecutive months during the Hawaiian skipjack season were compared (Table IX). Fig. 10 gives the average food volumes for samples for the months of May to September. There was a noticeable decrease in the average volumes of food for samples collected during mid-summer as compared to samples collected during late spring and early fall and the average volume of food followed very closely that of the fish fraction, which is not surprising, considering the contribution of fish to the diet. The decrease in the molluscan fraction from May to June contributes to the May to June decrease in total

Table VIII

Variation in the volume and composition of the stomach contents of skipjack caught within 9 miles of the Hawaiian Islands in relation to time of capture

Food organisms	Average volume (cc) per stomach				Percentage of occurrence				Percentage of total volume			
	Dawn to 0859	0900 to 1159	1200 to 1459	1500 to Dark	Dawn to 0859	0900 to 1159	1200 to 1459	1500 to Dark	Dawn to 0859	0900 to 1159	1200 to 1459	1500 to Dark
Crustaceans	.2	.9	.3	.7	28.0	31.6	14.3	34.6	2.6	4.9	3.5	5.5
Molluscs (total)	1.3	1.5	2.3	3.2	32.0	31.6	14.3	32.7	18.6	8.5	23.9	24.0
Squids	1.2	1.5	2.3	3.2	28.0	26.3	14.3	32.7	17.7	8.4	23.9	24.0
Other molluscs	.1	-	-	-	4.0	5.3	-	-	.9	-	-	-
Fish (total)	5.4	15.3	7.0	9.3	56.0	89.5	57.1	65.4	78.9	86.7	72.4	70.5
Sternoptychidae	.6	-	-	-	8.0	-	-	-	9.4	-	-	-
Synodontidae	.4	.5	-	.2	24.0	23.7	-	7.7	6.3	3.0	-	1.8
Myctophidae	-	1.7	-	-	-	2.6	-	-	-	9.6	-	-
Holocentridae	.1	1.5	-	.9	4.0	21.1	-	15.4	1.7	8.3	-	11.1
Carangidae	-	-	1.0	2.3	-	2.6	3.6	9.6	-	.1	10.1	17.8
Mullidae	.7	3.8	-	.1	8.0	36.8	-	3.8	9.9	21.6	-	.6
Chaetodontidae	.1	.1	-	.3	8.0	7.9	-	17.3	1.0	.6	-	2.1
Ammodytidae	.2	.6	.1	.7	4.0	10.5	2.6	21.2	2.3	3.5	.6	5.5
Acanthuridae	-	.8	-	.1	-	34.2	-	7.7	-	4.3	-	.5
Gempylidae	-	.2	.2	.3	-	13.2	8.6	15.4	-	1.4	1.9	2.3
Scombridae	-	.5	3.7	2.2	-	13.2	25.7	13.5	-	2.6	38.4	16.5
Molidae	-	3.3	-	-	-	15.8	-	1.9	-	18.9	-	.1
Other foods	-	-	-	-	-	-	-	-	-	-	-	-
All foods	6.9	17.6	9.7	13.2	92.0	94.7	57.1	84.6				
Number of stomachs examined	25	38	35	52								
Number of stomachs empty	2	2	15	8								
Average fork length (cm.)	43.5	48.5	46.5	46.3								
Average weights (lbs)	3.7	5.2	4.6	4.5								
Average volume (cc) food per pound of body weight	1.9	3.4	2.1	2.9								

Table IX

Variation in volume and composition of stomach contents of skipjack caught within 9 miles of the Hawaiian Islands in relation to month of capture

Food organisms	Average volume (cc) per stomach					Percentage of occurrence					Percentage of total volume				
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.
Crustaceans	1.0	.3	.1	.5	2.4	50.0	34.1	12.8	35.2	94.1	5.3	3.1	1.0	3.4	5.4
Molluscs (total)	6.3	2.8	3.5	4.3	.1	36.5	24.4	34.6	43.7	5.9	33.2	25.0	24.9	27.9	.3
Squids	6.3	2.8	3.5	4.3	.1	33.8	24.4	34.6	43.7	5.9	33.2	25.0	24.9	27.9	.3
Other molluscs	-	-	-	-	-	2.7	-	-	-	-	-	-	-	-	-
Fish (total)	11.7	8.2	10.5	9.8	40.2	82.4	73.2	74.4	67.6	70.6	61.5	71.8	74.1	64.0	90.3
Synodontidae	.1	-	.4	.1	-	4.1	-	19.2	7.0	-	.6	-	2.7	2.9	-
Myctophidae	-	-	-	.9	-	-	-	-	1.4	-	-	-	-	5.9	-
Holocentridae	-	-	-	1.8	.2	1.4	2.4	-	29.6	5.9	-	.2	-	11.8	.5
Carangidae	.9	-	3.0	.4	-	5.4	-	17.9	2.8	-	4.9	-	21.4	2.6	-
Mullidae	4.6	2.5	1.7	.4	1.5	32.4	22.0	14.1	7.0	5.9	23.9	22.0	12.0	2.6	3.4
Chaetodontidae	.8	-	-	.2	-	21.6	2.4	6.4	9.9	-	4.3	.2	.3	1.3	-
Ammodytidae	-	-	.5	.4	-	-	2.4	11.5	11.3	-	-	.4	3.4	2.9	-
Acanthuridae	-	-	.2	.3	-	-	2.4	10.3	12.7	-	-	.2	1.1	1.7	-
Gempylidae	2.1	.3	.4	.4	-	18.9	12.2	16.7	7.0	-	11.2	2.5	2.8	2.9	-
Scombridae	.5	2.4	2.2	.2	7.9	13.5	31.7	21.8	5.6	23.5	2.6	21.5	15.7	1.0	17.8
Nomeidae	-	-	-	1.5	-	-	-	-	8.5	-	-	-	-	9.7	-
Molidae	1.7	-	-	-	-	8.1	-	1.3	-	-	9.0	-	.1	-	-
Other foods	-	-	-	.7	1.8	-	2.4	1.3	7.0	35.3	-	-	-	4.8	4.1
All foods	19.1	11.4	14.1	15.3	44.4	97.3	78.0	84.6	91.5	100.0					
Number of stomachs examined	74	41	78	71	17										
Number of stomachs empty	2	9	12	6	0										
Average fork length (cm)	55.9	55.3	49.5	50.5	61.5										
Average weight (lbs)	8.5	8.2	5.6	6.0	11.6										
Average volume (cc) food per pound of body weight	2.2	1.4	2.5	2.6	3.8										

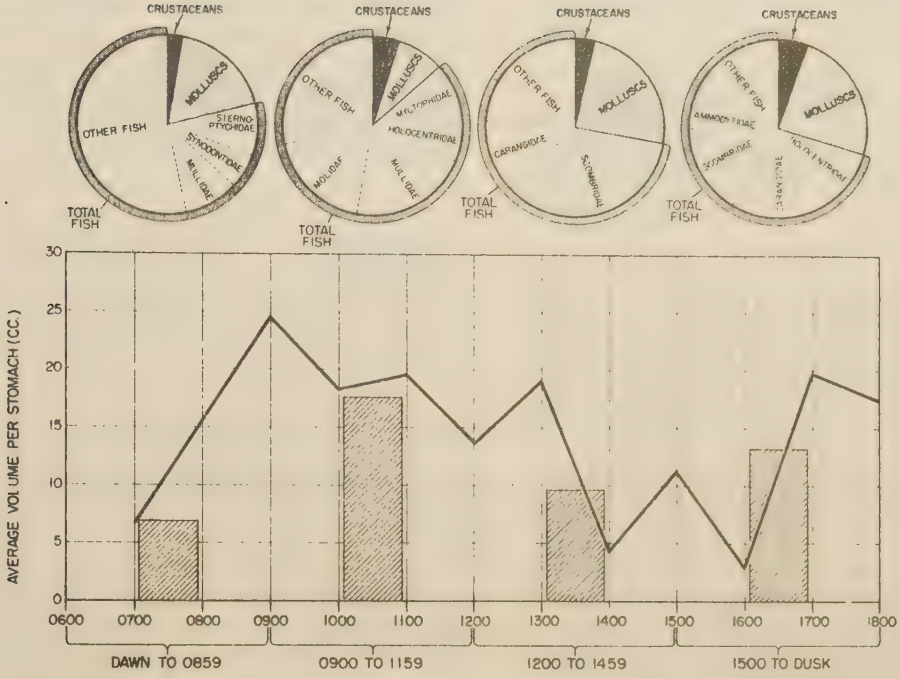

Fig. 9 Average food volume per skipjack stomach in relation to time (hour and time group) of capture, and variation in composition with time group. Sub-divisions of fish show those families which made up more than 5% of the total volume.

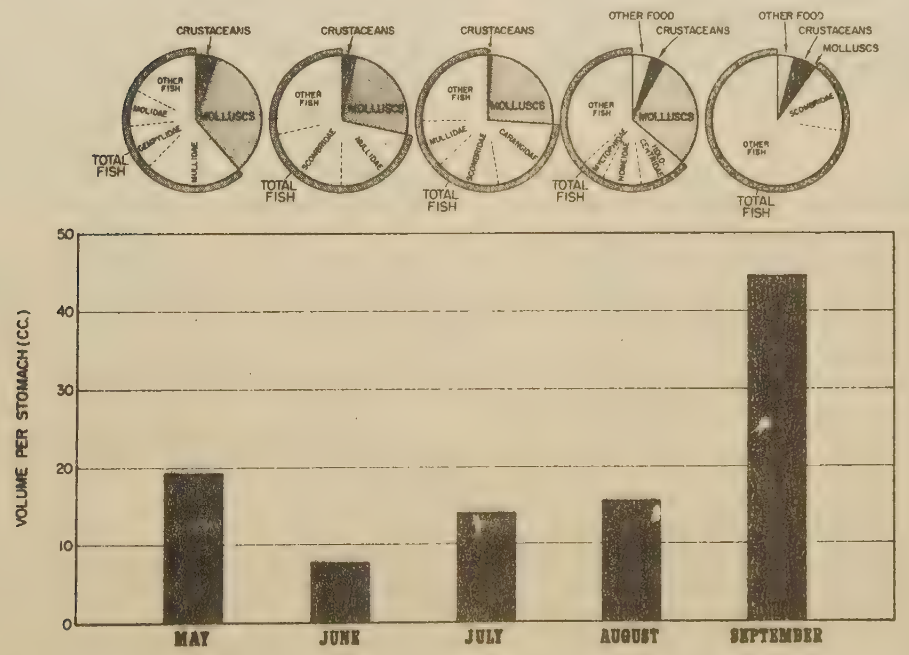

Fig. 10 Food volume per stomach and composition for skipjack caught within 9 miles of land in Hawaiian water related to month of capture.

volume, while the slight July to August increase in total food was due entirely to increases in the molluscan and crustacean fractions. It is difficult to ascertain the cause of this variation as it could have been due to one or a combination of the factors involved in this study. For example, there may be seasonal changes in the abundance of forage organisms, the size of forage organisms consumed may change with season, the general size of food organisms may change due to growth of the organisms, or there may be annual variations in the abundance of forage.

At present the methods of sampling the organisms which comprise the bulk of the food of skipjack are not satisfactory and relatively little is known concerning fluctuations in abundance of the food fauna. Zooplankton abundance (standing crop) has on occasion been used as indirect evidence of changes in abundance of forage organisms.[1] Although this may be generally so when applied to large areas of the ocean, when applied to smaller regional areas, zooplankton abundance need not necessarily reflect corresponding variations in the abundance of the larger food organisms, i.e., regional areas of equal zooplankton abundance need not have equal abundance of the larger food organisms. In the Hawaiian area, for example, Royce and Otsu (1955) showed an unequal distribution of skipjack schools between the windward and leeward sides of the island chain, while King and Hida (1954) found no significant differences between these same areas with respect to abundance of standing crop of zooplankton at any given time of the year. Because of this it is believed that the unequal distribution of skipjack is caused by some factor other than the abundance of zooplankton.

Analysis of the sizes and compositions of the food organisms shows for the Crustacea a shift from a variety of smaller organisms (average size about .2 cc) through May to August to stomatopods (average size .5 cc) in September; for the Mollusca, stability in composition but a decrease in size in September (4.0 to 1.0 cc); and for the Pisces, a shift from the smaller larval reef forms to the larger, more pelagic forms (2.0 cc to 20.0 cc).

Examination of the average lengths of skipjack from which stomachs were collected shows that with increase in length there is a corresponding increase in food volume. By interpolation of the average lengths of each group, from the results of the greater than 60 cm and less than 60 cm fish analysis, it was found that the variations of the adjusted volumes did not fully account for the larger variations in the average volumes of the monthly samples. Another possible source of the apparent seasonal variation is the unequal sampling by months during different years. Examination of Table I shows that the majority of the September samples were collected during 1954, while samples for May to August were collected during more than one year. If there are annual variations in the abundance of forage organisms, and this is not unlikely, then this might account for the abrupt peak in September. In this respect it is interesting to note that skipjack catches by the Hawaiian fishery during 1954 were the highest of any year in the 1948-61 period.

Another possibility lies in the rate of feeding during the spawning period. Of interest are the experiences of skipjack fishermen in relation to spawning skipjack. "Spawning schools" encountered during the skipjack season are difficult to fish and are usually abandoned for other schools (Yamashita, 1958). Certain fishes, such as the eel and salmon, stop feeding entirely during spawning migrations, and perhaps the same is true of the skipjack. From this the authors do not feel it unreasonable to presume that the rate of feeding may possibly decrease somewhat before the actual period of spawning. According to the results of the ovarian studies by Brock (1954), a greater number of Hawaiian skipjack may be spawning during the summer months, with a peak perhaps near the mid-summer months.

5 SUMMARY AND CONCLUSIONS

(1) This report is based on the analyses of the stomach contents of 707 skipjack, Katsuwonus pelamis (Linnaeus) taken from the Hawaiian, Line, and Phoenix Islands areas.

(2) The stomach samples were collected during the years 1950-56 by six vessels from a total of 41 cruises and by four different fishing methods: troll (66), purse seine (25), pole-and-line (496), and longline (120).

(3) The food of skipjack consisted of fish (75 percent by volume), squid (20 percent), and crustaceans (4 percent).

(4) General comparisons with the food of yellowfin and bigeye showed, for all three species, utilization of a great variety of organisms. Fish of the family Scombridae were the most important factor for skipjack, while Gempylidae

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[1] It is perhaps of interest here that analysis by E. L. Nakamura of the abundance of zooplankton in Hawaiian waters during 1956 reveals a slight decrease in plankton volumes during the mid-summer as compared to late spring and early autumn.

constituted the largest single element among the fish families in terms of food value for yellowfin and bigeye.

(5) Larval and juvenile tuna composed a high percentage of food of skipjack and were also prominent in the food of yellowfin but scarce in that of bigeye.

(6) Relative food values of the more important fish families showed inverse relationships, which somewhat reflects the horizontal and vertical distributions of these fish families, when comparing the foods of bigeye, yellowfin and skipjack.

(7) The skipjack depended to a lesser extent on squid and to a greater extent on fishes as sources of food than did the yellowfin and bigeye.

(8) No significant variation in the major food groups (Crustacea, Mollusca and Pisces) was noted with increase in size except for changes in the composition of the crustacean and fish groups to a more pelagic type.

(9) Average food volumes for troll-caught samples were markedly lower than those for skipjack taken by pole-and-line.

(10) The subsurface fish showed a greater dependency on the squid fauna as a major source of food but with a lower average food volume per stomach than the surface fish, which may indicate that the subsurface level may be poorer in food fauna, causing the larger-sized subsurface fish to search for food throughout a considerable range of depth.

(11) Distance-from-land analysis showed no great variation in the major food groups, with Pisces important throughout; the importance of the different fish families varied with distance from land.

(12) In respect to areas of capture, skipjack from Hawaiian waters showed greater dependency on fishes as source of food than the others; those from near the Phoenix Islands showed an increased dependency on squid, and those from the Line Islands on Crustacea.

(13) Analysis by time of capture gave no indication of preference for food significant enough to influence the diurnal behavior and migrations of skipjack.

(14) Fluctuations in the rate of feeding (food volume) and variations in the consumption of the major food groups (composition) are probably more closely related to the diurnal behavior and migrations of the food fauna than to those of the skipjack.

(15) The average food volume per stomach of Hawaiian skipjack varied during the mid-summer months and increased abruptly in September, perhaps due to uncontrolled variables present in the sampled groups or to variations in composition of food fauna or the rate of feeding during spawning.

Appendix Table I

Food organisms	Number of organisms	Stomachs in which occurred		Aggregate total volume		
		Number	Percent	Cubic centimeters	Percent	Average volume per stomach
ARTHROPODA						
Crustacea	2610	255	36.1	518.2	3.7	.7
Unidentified	2	6	.9	16.6	-	-
Copepoda	-	1	.1	5.0	-	-
Malacostraca						
Peracarida						
Mysidacea						
Mysiidae	11	1	.1	.6	-	-
Isopoda	7	4	.6	6.2	-	-
Amphipoda					.6	.1
Unidentified	366	71	10.0	41.9	.3	.1
Hyperiidae	98	10	1.4	30.0	.2	-
Phronimidae						
Phronima sp.	27	15	2.1	9.1	.1	-
Phrosinidae	3	1	.1	1.0	-	-
Pronoidae	2	1	.1	1.0	-	-
Oxycephalidae						
Oxycephalus sp.	5	3	.4	.3	-	-
Eucarida						
Unidentified	7	7	1.0	3.0	-	-
Euphausiacea						
Euphausiidae					0.6	.1
Unidentified	127	7	1.0	18.8	.1	-
Thysanopoda						
Unidentified	1	1	.1	.1	-	-
Thysanopoda tricuspidata	530	4	.6	67.4	.5	.1
Euphausia	9	1	.1	2.0	-	-
Decapoda					0.7	
Unidentified	25	12	1.7	5.1	-	-
Natantia						
Unidentified	90	1	.1	10.0	.1	-
Pandalidae						
Heterocarpus ensifer	1	1	.1	.5	-	-
Reptantia						
Scyllaridae						
Phyllosoma larvae	2	2	.3	1.1	-	-
Nephropsidae						
Enoplometra						
Unidentified	3	3	.4	1.1	-	-
Enoplometra occidentalis	3	1	.1	1.0	-	-
Brachyuran megalops	595	94	13.3	76.8	.6	.1
Hoplocarida						
Stomatopoda					1.5	.3
Squillidae						
Unidentified	346	89	12.6	119.4	.9	.2

Appendix Table I (con.)

Food organisms	Number of organisms	Stomachs in which occurred		Aggregate total volume		
		Number	Percent	Cubic centimeters	Percent	Average volume per stomach
Squilla sp.	188	14	2.0	23.6	.2	-
Pseudosquilla						
Pseudosquilla ciliata	5	3	.4	2.5	-	-
Pseudosquilla occulata	1	1	.1	1.0	-	-
Lysiosquilla sp.	85	21	3.0	31.6	.2	-
Coronida sp.	54	13	1.8	32.2	.2	.1
Gonodactylus sp.	5	3	.4	3.1	-	-
Odontodactylus						
Unidentified	1	1	.1	.6	-	-
Odontodactylus hanseni	11	3	.4	5.5	-	-
MOLLUSCA						
Gastropoda						
Unidentified	-	1	.1	.5	-	-
Heteropoda						
Unidentified	1	1	.1	4.0	-	-
Atlantidae						
Atlanta sp.	1	1	.1	.1	-	-
Pteropoda						
Unidentified	9	3	.4	2.1	-	-
Carolinidae						
Carolinia sp.	23	6	.9	4.6	-	-
Cephalopoda						
Octopoda						
Unidentified	27	5	.7	22.9	.2	-
Argonautidae	19	10	1.4	23.9	.2	-
Decapoda (squid)	640	245	34.7	2726.9	19.5	3.9
Unidentified	579	233	33.0	2357.7	16.9	3.3
Loliginidae						
Unidentified	11	6	.9	118.2	.9	.2
Sepioteuthis sp.	1	1	.1	34.8	.3	.1
Ommastrephidae						
Unidentified	41	5	.7	106.4	.8	.2
Ommastrephes hawaiiensis	3	2	.3	89.5	.6	.1
Symplectoteuthis sp.	5	2	.3	20.3	.2	-
CHORDATA						
Tunicata						
Unidentified	1	1	.1	1.0	-	-
Salpidae	1	1	.1	1.0	-	-
Vertebrata (Pisces)	2827	474	67.0	10,422.2	74.6	14.7
Unidentified	631	217	30.7	2472.8	17.7	3.5
Albulidae	5	4	.6	39.4	.3	.1
Clupeidae						
Unidentified	12	6	.9	56.9	.4	.1
Etrumeus micropus	5	3	.4	44.2	.3	.1

Appendix Table I (con.)

Food organisms	Number of organisms	Stomachs in which occurred		Aggregate total volume		
		Number	Percent	Cubic centi - meters	Percent	Average volume per stomach
Sternoptychidae						
Unidentified	49	4	.6	81.9	.6	.1
Sternoptyx diaphana	45	3	.4	39.0	.3	.1
Stomiatidae	2	2	.3	37.0	.3	.1
Synodontidae	119	24	3.4	48.7	.4	.1
Paralepidae	1	1	.1	8.1	.1	-
Alepisauridae						
Alepisaurus borealis	3	3	.4	12.2	.1	-
Myctophidae						
Unidentified	136	5	.7	112.8	.8	.2
Diaphus sp.	12	1	.1	64.0	.5	.1
Scomberesocidae						
Cololabis sp.	4	4	.6	93.7	.7	.1
Hemirhamphidae	2	2	.3	4.5	-	-
Exocoetidae						
Unidentified	13	11	1.6	150.0	1.1	.2
Parexocoetus brachypterus	1	1	.1	.5	-	-
Fistulariidae	1	1	.1	1.0	-	-
Syngnathidae						
Unidentified	7	7	1.0	3.4	-	-
Hippocampus sp.	3	1	.1	1.4	-	-
Holocentridae						
Unidentified	91	27	3.8	168.2	1.2	.2
Holocentrus sp.	11	8	1.1	28.1	.2	-
Sphyraenidae	3	2	.3	6.0	-	-
Atherinidae	2	1	.1	2.0	-	-
Kuhliidae	2	1	.1	63.0	.5	.1
Priacanthidae						
Priacanthus cruentatus	1	1	.1	5.6	-	-
Scombropidae	6	3	.4	9.0	.1	-
Carangidae						
Unidentified	2	2	.3	6.1	-	-
Decapterus						
Unidentified	39	25	3.5	565.8	4.1	.8
Decapterus pinnulatus	4	3	.4	137.0	1.0	.2
Scomberoides sanctipetri	1	1	.1	1.0	-	-
Trachurops crumenophthalus	1	1	.1	15.0	.1	-
Bramidae						
Unidentified	27	12	1.7	92.6	.7	.1
Collybus drachme	2	2	.3	1.2	-	-
Coryphaenidae						
Coryphaena hippurus	2	2	.3	19.0	.1	-
Mullidae						
Unidentified	339	53	7.5	604.8	4.3	.9
Mulloidichthys						
Unidentified	1	1	.1	20.0	.1	-
Mulloidichthys auriflamma	43	5	.7	89.9	.6	-
Chaetodontidae	148	49	6.9	138.6	1.0	.2

Appendix Table I (con.)

Food organisms	Number of organisms	Stomachs in which occurred		Aggregate total volume		
		Number	Percent	Cubic centimeters	Percent	Average volume per stomach
Pomacanthidae	20	11	1.6	10.5	.1	-
Blenniidae	2	2	.3	3.7	-	-
Brotulidae	14	3	.4	12.7	.1	-
Ammodytidae						
Unidentified	54	15	2.1	52.4	.4	.1
Bleekeria sp.	36	4	.6	19.6	.1	-
Acanthuridae	80	34	4.8	71.2	.5	.1
Gempylidae						
Unidentified	56	30	4.2	177.8	1.3	.3
Gempylus serpens	114	60	8.5	268.8	1.9	.4
Scombridae						
Unidentified	35	16	2.3	100.1	.7	.1
Scomber sp.	13	3	.4	23.2	.2	-
Katsuwonus pelamis	235	55	7.8	3153.1	22.6	4.5
Euthynnus yaito	9	4	.6	178.6	1.3	.3
Neothunnus macropterus	10	2	.3	31.6	.2	-
Scomberomoridae	1	1	.1	3.4	-	-
Tetragonuridae	1	1	.1	1.0	-	-
Nomeidae						
Unidentified	4	2	.3	86.2	.6	.1
Cubiceps sp.	172	23	3.3	419.2	3.0	.6
Scorpaenidae						
Unidentified	11	5	.7	9.2	.1	-
Pontinus sp.	22	9	1.3	14.4	.1	-
Scorpaena sp.	3	2	.3	5.0	-	-
Setarchus sp.	1	1	.1	1.0	-	-
Balistidae						
Unidentified	2	2	.3	3.1	-	-
Balistes ringens	1	1	.1	2.0	-	-
Monacanthidae	8	5	.7	8.6	.1	-
Ostraciidae						
Unidentified	1	1	.1	.1	-	-
Ostracion diaphana	4	2	.3	4.0	-	-
Tetraodontidae	5	5	.7	11.4	.1	-
Diodontidae						
Unidentified	1	1	.1	7.0	.1	-
Diodon holacanthus	11	1	.1	3.0	-	-
Canthigasteridae	1	1	.1	.2	-	-
Molidae						
Unidentified	8	7	1.0	127.1	.9	.2
Ranzania truncata	116	20	2.8	336.8	2.6	.5
Unidentified remains	-	37	5.2	246.6	1.8	.4
Total food	6159	625	88.4	13974.0		19.7
Number of stomachs examined	707					

Experience Paper No. 27

EFFECTS OF WATER TEMPERATURE ON THE DISTRIBUTION OF SOME SCOMBRID FISHES ALONG THE PACIFIC COAST OF NORTH AMERICA

By

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Abstract

In 1926, the waters off the California coast warmed up, bringing many southern species into the area. Despite documentation of this, and a similar phenomenon during another warm-water year, 1931, as well as a detailed discussion of the subject published in 1948, interest cooled after 1948 as the waters cooled. A re-awakening occurred during the recent warm-water period beginning in 1957. After much evidence was accumulated, the concept that water temperatures strongly influence fish distributions began gaining general acceptance. During the latter warm-water period, the biological ranges were extended for California bluefin tuna, Pacific yellowfin tuna, and Pacific bigeye tuna, and equaled for skipjack tuna. Relationships were demonstrated between water temperatures and the distributions of four species of tuna and Pacific bonito. In addition, the author shows that the effect of temperature on the California catch-per-effort of species which move up and down the coast may be described by the left limb of a bell-shaped curve.

EFFETS DE LA TEMPERATURE DE L'EAU SUR LA DISTRIBUTION DE CERTAINS SCOMBRIDES LE LONG DE LA COTE PACIFIQUE DE L'AMERIQUE DU NORD

Résumé

En 1926, un réchauffement des eaux baignant la côte californienne a provoqué l'apparition dans la région de nombreuses espèces de poissons des zones australes. Des documents ont été publiés sur ce point, et l'année 1931, durant laquelle la température des eaux a de nouveau augmenté, a vu une répétition du phénomène; en outre, une étude détaillée de la question a paru en 1948. En dépit de ces faits, l'intérêt porté à la question

a diminué après 1948, tandis que la température décroissait. Une autre période de réchauffement ayant commencé en 1957, le sujet a provoqué un renouveau d'intérêt. Après qu'eut été rassemblée une masse de documentation, la notion selon laquelle la température de l'eau exerce une forte influence sur la distribution géographique des poissons a commencé à se répandre. Par rapport aux latitudes enregistrées précédemment, l'aire de répartition a, durant cette dernière période de réchauffement, connu une extension pour le thon rouge, le thon à nageoires jaunes et le thon obèse, et atteint les mêmes valeurs pour la bonite à ventre rayé. L'existence d'un rapport a été établie entre la température de l'eau et la distribution de quatre espèces de thons et de la bonite du Pacifique. L'auteur démontre également que, pour ce qui est de la pêche californienne, l'effet de la température sur les captures par unité d'effort pour les espèces se déplaçant le long de la côte peut être figuré par la branche ascendante d'une courbe en cloche.

EFECTOS DE LA TEMPERATURA DEL AGUA SOBRE LA DISTRIBUCION DE ALGUNOS ESCOMBRIDOS A LO LARGO DE LA COSTA DEL PACIFICO DE AMERICA DEL NORTE

Extracto

En 1926, las aguas de la costa de California aumentaron de temperatura, lo que permitió la llegada a dicha zona de muchas especies meridionales. A pesar de la documentación existente sobre éste y otro fenómeno similar producido durante otro año de aguas templadas, como fue el 1931 así como de una discusión detallada sobre la materia publicada en 1948, el interés sobre tal cuestión se enfrió después de 1948 a medida que descendió la temperatura de las aguas. Se registró una nueva reavivación durante el reciente período de aguas cálidas que comenzó en 1957. Después de haberse reunido muchos datos comenzó a ser admitido por todos el concepto de que la temperatura del agua influye grandemente sobre la distribución de los peces. Durante el último período de agua caliente se ampliaron los márgenes biológicos para los atunes californianos de aleta azul, aleta amarilla y patudo, y se unificaron para el barrilete. Se demostraron las relaciones existentes entre las temperaturas del agua y la distribución de cuatro especies de atún y de bonito del Pacífico. El autor demuestra, además, que el efecto de la temperatura sobre la captura en relación con el esfuerzo en California de especies que se mueven hacia el norte y sur de la costa puede ser expresado por la rama izquierda de una curva acampanada.

1 REVIEW OF PREVIOUS STUDIES

1.1 Early concepts

For almost as long as fishing has been conducted off the North American west coast men have speculated on the causes of good and poor fishing and the reasons for sudden unpredicted occurrences of certain fish.

A record of their speculations is not available since most of these ideas were expressed orally or else remained in the minds of their originators. However, an occasional written remark suggests a long history of man's awareness of the possible effects of environment on fish distribution.

Thompson (1919) quoted from a letter received from Captain A. C. Tibbetts, describing the occurrence of albacore (Thunnus germo) off northern California on September 22, 1884. The quotation is, in part, as follows:

> "While running for Humboldt Bar, at four to five knots speed, somewhere between Redding Rock and Trinidad Head, I noticed fish working the same as they sometimes do on the coast of southern California, and out of curiosity threw a cod line with a white rag on the hook over the stern, and when the line straightened out got an albacore. Caught three, as fast as they could be unhooked and the line put out again. The fish appeared to be abundant, but those taken were dirtying things up around the after part of the deck, so fishing was stopped."

Thompson (1919) continued as follows:

> "Captain Tibbetts is familiar with albacore, having taken them south of San Francisco. He believes the long southerly blow had reversed the usual coastal current and brought warmer water with it.
>
> "He also (October 17, 1883) records the occurrence of skipjacks (presumably Euthynnus) in considerable numbers 120 miles west of Trinidad - - - - - -."

In addition to noting tuna off northern California in 1883 and 1884, Captain Tibbetts has inferred that they were distributed northward because of warmer water. He also suggests that the warm water may have been carried by a wind driven counter-current.

1.2 Studies in 1917

Thompson (1917) made the first scientific attempt to relate catches of fish off the Pacific coast of North America to water temperatures. He was impressed by studies conducted at that time which revealed that activity and feeding behavior of cold-blooded vertebrates were influenced by temperature. He felt that the albacore catch should be related to the temperature since, being caught entirely on bait and trolled jigs, their landings would reflect their activity and hunger.

Ocean temperatures were not available, so he compared the mean minimum air temperatures at San Diego with the average daily boat catch at San Diego. He also compared the average daily boat catch at San Pedro with the mean minimum air temperatures at Avalon and at Santa Barbara.

He maintained that greater catches were made at Santa Barbara when temperatures there were high relative to those at Avalon, and when Santa Barbara's temperatures were low relative to Avalon's, catches were greater to the south.

His observations were confined entirely to the inshore area of southern California during one season, 1916. Although the paper was to have been a preliminary report, the final report was never published, and his data have never been made available. From his three figures, it appears the relationship between the total San Pedro catch and the mean minimum air temperature at Santa Barbara is better than the other relationships he discusses. With the absence of data, his strong claims regarding the significance of his correlations are not substantiated by the graphs appearing in his paper.

With regard to the local absence of albacore during winter he states:

> "It would appear logical, then, to ascribe the disappearance of the fish to climatic conditions, rather than migration."

Although his first paragraph carries the strong statement,

> "Rarely, in so far as the writer knows, has there been found a case in which the correlation is as evident and clearly cut",

it is somewhat offset by the statement appearing in his last paragraph:

> "The present paper is intended above all as an indication of what might be discovered if adequate facts and statistics were at hand."

1.3 Warm-water years of 1926 and 1931

The next reference to an unusual distribution of tuna along the California coast (Anonymous, 1925) described large catches of albacore made in August and September, 1925, near San Francisco. The prospects of developing a fishery and opening a cannery in San Francisco were discussed; however, after 1926, catches off central California dropped markedly.

Hubbs and Schultz (1929) pointed out that the abundance of albacore off San Francisco and Monterey during 1925 and 1926 was associated with the occurrence of exceptionally warm water and that few albacore were caught off central California during the cooler years from 1916 through 1924. They produced the first well-documented arguments on the effect of water temperature on fish distributions along the North American Pacific coast and, in addition, recorded occurrences of several species of fish north of their usual ranges.

By the time the waters off the California coast warmed up again, the effect of water temperature on the latitudinal distribution of fish had been demonstrated. However, Walford (1931) further documented the northward occurrences of southern fish in 1931 and showed that air temperatures at San Diego and Los Angeles were considerably above average during the winter of 1930-31 and the spring and summer of 1931.

Skogsberg (1939) indicated that the shift of the population of white seabass, *Cynoscion nobilis*, from off San Francisco in 1889 to south of Point Conception by 1939 was probably associated with changes in environmental conditions. He also indicated that the upsurge in landings at Monterey in 1926 was probably due to the unusually warm water occurring that year.

1.4 Temperature depression after 1947

A detailed discussion by Hubbs (1948), demonstrated that prehistoric changes, long-period displacements, and single-season northward dispersals of fish fauna were correlated with ocean temperature. Hubbs stated:

> "--- it seems safe to assert that the distribution of marine fishes along the Pacific coast of North America is determined to a large degree by the sea temperatures."

Hubbs also mentioned that albacore were looked for at temperatures approximately 60° to 65° F (15.5° to 18.4° C).

Despite the evidence accumulated up to 194 the ocean climate had just entered a nine-year series which was to be the longest run of subnormal temperatures recorded at Scripps Pier in 40 years. During this cold period, much of the evidence regarding relationships of fish distri bution to water temperatures was ignored and al most forgotten as fishing for many species declined progressively. The poorer fishing creat considerable anxiety and focused attention on overfishing as a possible cause of the decline. Although many oceanographers had felt environme was extremely important in determing the size distribution of fish populations, they still we reluctant to consider a direct relationship between temperature and fish. Since temperature the factor most easily obtained, among innumer others, the unsophisticated approach of consid ing it as a primary cause governing fish distr tion was regarded with some contempt. With no warm water and no intrusions of warm-water spe little was happening to inspire an investigati in this direction.

1.5 Warm-water years of 1957, 195 and 1959

The abrupt rise of ocean temperatu off the west coast of North America in 1957 and the accompanying influx of wa water species prompted a reconsiderati of temperature effects on fish distrib tion. Fish responded more quickly tha oceanographers to the changing ocean c mate. As early as March 1957 exceptio ly good catches of California yellowta *Seriola dorsalis*, were made by angler fishing at Los Coronados Islands. By April, the author had become intereste in this phenomenon and began keeping record of northerly occurrences of sou thern species and comparing catch dat with temperatures. A preliminary rep of this work appeared in the Californ Cooperative Oceanic Fisheries Investi tions Progress Report, 1 July 1956 to 1 January 1958 (pages 9 through 14) i section the author submitted entitled "California Department of Fish and Ga (Calif.Coop.Ocean.Fish.Inv. 1958). A multilithed report (Calif.Mar.Res.C 1957) which previewed the highlights the Progress Report also contained th preliminary report of the author's fi ings.

In June 1957, the California Department Fish and Game research vessel, *N. B. Scofiel* made an exploratory cruise in an attempt to cept incoming albacore schools. The vessel countered water temperatures higher than the mum of 60° to 65° F (15.5 to 18.4° C) as sailed southward. Kenneth F. Mais, biologi charge of the cruise, shifted the survey no ward and caught the first albacore of the s about 80 miles WNW of Guadalupe Island in water temperatures of 62° F (15.6° C). The fishery began in this northerly area and ranged farther north in July than during the Julys of the six previous seasons (Radovich, 1960).

In November 1957, Clemens (1957) published a popular article discussing albacore predictions. He pointed out that most albacore were caught between 60° and 64° F (15.5° and 17.8° C). He also indicated that when albacore migrated northward far offshore, they were out of range of many boats, particularly the sportfishing vessels; and when most of the run is closer to shore, sportfishing for albacore is good. He felt that the variation in proximity to the coast was due to water temperature.

Despite the confirmation of concepts demonstrated 10 to 30 years earlier, biologists and oceanographers were still reluctant to accept the idea of a direct relationship between fish distribution and temperature as late as June 1958. This is apparent in the discussion following the author's presentation on this subject at a symposium (The Changing Pacific Ocean in 1957 and 1958) at Rancho Santa Fe on July 2-4, 1958 (Radovich, 1960). Just prior to this meeting, on the basis of isotherms for the eastern north Pacific, Clemens (1958) had predicted:

> "We believe that this year most of the albacore will hit the coast even farther north than last year."

Subsequently, the fishery developed as predicted. Those fishermen who headed for their traditional southerly areas did not catch fish until they shifted to the north (Radovich, 1961).

The author also pointed out, at the Rancho Santa Fe meeting (Radovich, 1960) that California bluefin tuna, (Thunnus saliens), usually caught only south of Point Conception, were caught off Monterey between July and October in the warm-water year, 1957. Catches were also made from 80 to 100 miles north of Cape Flattery off Eureka and off Newport, Oregon. In addition, skipjack tuna, (Katsuwonus pelamis), Pacific yellowfin tuna (Neothunnus macropterus), and Pacific bonito, (Sarda chiliensis), were caught far north of their usual range, and the range of yellowfin tuna was extended northward by two specimens; one caught on August 18, 1957 off Pt. Buchon and the other on September 25, 1957 off Davidson Seamount.

Following the Rancho Santa Fe symposium (Calif.Coop.Ocean.Fish.Inv. 1960) the concept that water temperatures could affect fish distribution gained more general acceptance.

In May 1959, Radovich (1959) published a popular article describing the effect of ocean temperatures on sportfishing. About the same time, numerous papers were published referring to warm water and its influence on fish catches. The persistence of the warm-water period through 1959, with continued good fishing had convinced most fisheries biologists as well as sport and commercial fishermen that temperature was a factor to be considered.

In May 1959, Craig (1959) predicted that the albacore fishery would begin to the north again. The Department of Fish and Game vessel N.B. Scofield departed on June 1, 1959, to scout for incoming schools and on June 5, encountered the season's first albacore about 90 miles WxN of Point Arguello. Simultaneously, the U.S. Fish and Wildlife Service vessel Hugh M. Smith ran a scouting pattern south of the N.B. Scofield but caught no fish (Craig and Graham, 1961). The fishery developed in the northern area.

In May 1959, Neave (1959) reported California bluefin tuna in British Columbia waters. One was taken at lat.49° N, long. 134° 24' W, about 260 miles west of Vancouver Island on August 25, 1957, and another at lat. 48° 50' N, long. 131° 06' W, about 150 miles west of Vancouver Island on August 28, 1957, both by the Canadian vessel Fort Ross. On August 8, 1958, a third bluefin tuna was caught by the Canadian vessel Key West II, at lat. 51° N, long. 130° W, near the north end of Vancouver Island. These three bluefin were the first ever recorded off British Columbia.

Neave (1959) also reported the second skipjack from British Columbian waters. It was caught by E. Olafsen on September 16, 1958 in a gill net at the entrance of Juan de Fuca Strait.

Although Neave did not mention it, these tuna captures happened during warm-water years.

In May 1960, Craig (1960) predicted that the cooler sea temperatures should shift the albacore run a little to the south. He said :

> "We believe, however, that sea temperatures are still too warm (about 62° F at Guadalupe Island) to expect the incoming schools to follow their pre-1957 pattern to the south of Guadalupe Island."

Again in 1960, the fishery developed in the area predicted.

Regarding the problem of predicting where to expect albacore to appear along the North American west coast, Johnson (1960) writes:

> "Biologists from the California Department of Fish and Game have made excellent strides in solving this latter problem by making pre-season scouting cruises and by predicting the appearance of the albacore on the basis of catches from this cruise and from water temperature.
>
> "The value of sea-temperature as a forecasting tool of albacore distribution has been amply demonstrated during the last four years."

Johnson pointed out that radar picket ships stationed off the west coast of the United States were trolling for albacore in cooperation with the U.S. Bureau of Commercial Fisheries Tuna Oceanography Program. In 1960 the first albacore caught by the picket vessels were taken 5 June on the southermost station. Subsequently, catches progressed up the coast. He noted that albacore arrived at the two southermost stations about the same time as the 61° F (16.1° C) isotherm.

In 1960, the author submitted a paper documenting the northern occurrences of southern species in 1957, 1958 and 1959 demonstrating the effect of temperature on some species, correlating fishing success with temperature for some species, and advancing hypotheses on the influence of temperature on behavior of some species (Radovich, 1961).

The author pointed out that during the warm-water years 1957, 1958 and 1959, skipjack tuna, California bluefin tuna, Pacific yellowfin tuna, Pacific bigeye tuna (Parathunnus sibi), and Pacific bonito were all caught north of their usual range, and that the Pacific albacore fishery began farther north than usual. Geographic ranges were extended northward for three species: bluefin tuna, to Wide Bay, off Shelikof Straits north of Kodiak Island, Alaska, on July 28, 1958; yellowfin tuna, by the two specimens mentioned previously; and bigeye tuna, on July 13, 1959 to Iron Springs, Washington. The first bigeye tuna recorded from California was caught on September 16, 1959 about 90 miles west southwest of Cape Mendocino. The sportcatch of bonito increased dramatically during the warm years.

In the southern hemisphere the El Niño condition prevailed during 1957 and 1958 and water temperatures off Chile reached the highest in 18 years. The Chilean albacore catch was the poorest in many years, being only about 15 percent of the recent average when water temperatures were much lower (Radovich, 1961).

The distribution of each of the scombrids mentioned was affected by temperatures. In all probability, the northerly coastal penetration of each is a function of ocean temperatures along the coast.

In June 1961, Clemens (1961) summarized the progress made from 1951 to 1958, by California Department of Fish and Game marine biologists in their study of North Pacific albacore stocks. He described variations in migration up the coast and in the coastward migration. He pointed out that sea temperature is one of several important factors regulating their movements and distribution. He showed that almost 90 percent of 1.3 million fish samples were caught where surface temperatures were 60° to 67° F (15.5° to 19.4° C). He indicated that small fish were caught near the surface while larger fish were caught in deeper cooler water where surface temperatures were warmer. He stated that a similar relationship exists in the western Pacific.

In August 1961, Alverson (1961) showed that commercial albacore fishing offshore from Oregon, Washington and British Columbia occurs during summer months when offshore surface water temperatures exceed 58° F (14.4° C). He indicated that albacore probably inhabit only the warmer surface layer above the thermocline. He also stated that concentrations appear to occur along the interface of the warm oceanic waters and the cooler waters adjacent to the coast.

In August 1961, Johnson (1961) found that in years with above-normal ocean temperatures, albacore landings in Oregon and Washington were, in general, significantly greater than in years with below-normal temperatures. Although warm water did not insure a good fishery, widespread cold water had a negative effect on the success of a season. He indicated that if the June sea temperature anomaly is large enough, it is possible to predict if sea temperatures would be favorable for albacore at the beginning of the fishery in mid-July.

Hester (1961) attempted to predict the 1960 albacore and bluefin tuna catches by using coastal sea-surface temperatures. He showed that the most productive bluefin tuna fishing area was off central Baja California during the Augusts of 1952 and 1953 (two cold years) and off southern California during the Augusts of 1957 and 1958. However, he did not present data for other years or other months. He found the California landings of yellowfin, skipjack and bluefin tuna caught north of the International Border covaried over the years and varied inversely with albacore landings from south of the border. He compared albacore catches from south of the International Border and bluefin tuna catches from California with temperature. On the basis of the resulting linear relationships he predicted the bluefin tuna catch from California and the albacore catch from south of the International Border.

His attempt to predict the catch is commendable; however, it is doubtful that fiducial limits can be set for these data, since it is not known to what extent consecutive annual observations are randomly distributed. At any rate, his limits of 3.2 to 12.8 million pounds accompanying his prediction of 8.0 million pounds for the California bluefin tuna catch seem to have blanketed the a actual catch of 4.3 million pounds (Calif. Dept.Fish and Game, 1961). His prediction of 13.9 million pounds of albacore from south of the International Border with his "confidence limits at the 66 percent level" of 8.5 to 19.3 million pounds, missed by by quite a margin. Only 3.0 million pounds were landed from south of the State.

1.6 Résume

We have seen that man has been aware of the influence of environment on fish distribution for a long time. Intrusions of southern species into northern areas seem to trigger interest in this phenomenon; it wanes quickly, however, when waters cool and southern species retreat. During each succeeding warm period man again senses the relationship between temperature and fish distribution. No real progress was made in this study, however, until these redistributions were first documented (Hubbs and Schultz, 1929). Even after documentation of a second warm-water period (Walford, 1931) and a detailed discussion of the phenomenon (Hubbs, 1948), interest in the relationship of fish distribution to water temperatures declined as the water cooled. Another warm period beginning in 1957 provided the stimulus for further documentation and studies (Radovich, 1959 1960 and 1961). As the warm period continued and evidence accumulated, the concept became generally accepted. It is interesting to note, but not surprising, that the relationships of fish distribution to water temperature are now being taken for granted and a general feeling is developing that they have been known all the time.

2 SOME ADDITIONAL RELATIONSHIPS

2.1 Skipjack and yellowfin tuna

If we compare the California catches of skipjack and yellowfin tuna (Table I, Fig. 1) we see, as did Hester (1961), that catches for both species were high in 1946, then dropped in 1947 and 1948, were low from 1951 through 1956, and were high during the three warm years 1957, 1958 and 1959. An examination of the average sea-surface temperatures during the first half of each year (January through June) at Scripps Pier, La Jolla, California, shows that water temperatures dropped after 1947, remained lower through 1956, increased considerably in 1957, 1958 and 1959 and dropped again in 1960. (Table II, Fig.2). These temperatures were used since they closely reflect the average temperatures of the broad area within the 5-degree square lat. 30°-35° N, long. 115°-120° W (Radovich, 1961).

The similarity of the two catch curves suggests that both species responded to the environment in the same manner. However, an apparent aberrancy exists between the year of peak temperature and the year of peak catch for both species. Several things could cause this. Three of the most obvious are: the average sea-surface temperature at Scripps Pier during the first half of the year may not be an accurate indicator of the environment to which the species are responding; the total population sizes may have varied; and local catches of bluefin tuna and skipjack may be strongly influenced by things other than the proportion of fish north of the International Border, such as economic conditions, or fish behavior.

TABLE I

California Tuna Landings in Thousands of Pounds
i.e. (000) Omitted

	From North of the Mexican Border				Total Landed in California		Proportion From North of the Mexican Border	
Year	Skipjack	Yellowfin	Bluefin	Albacore	Bluefin	Albacore	Bluefin	Albacore
1945	93.08	4.96	14,138.09	9,074.16	20,594.11	21,336.20	.687	.425
1946	1,747.06	32.65	15,529.23	9,105.89	22,031.75	18,068.34	.705	.504
1947	893.05	3.32	14,755.62	7,664.92	20,837.63	13,427.28	.708	.571
1948	319.19	0.41	1,693.76	10,554.56	6,696.99	36,481.01	.278	.289
1949	26.68	9.88	2,266.16	20,583.57	4,389.39	44,163.13	.517	.466
1950	12.42	1.46	9.34	38,217.02	2,738.96	61,821.18	.004	.618
1951	0.59	0.00	837.18	13,293.76	3,862.39	30,915.34	.218	.430
1952	0.53	0.00	907.22	23,105.73	4,576.68	49,802.79	.199	.464
1953	1.28	0.10	3,903.64	13,345.10	9,772.62	33,835.90	.399	.394
1954	14.40	0.00	5,647.57	14,289.10	21,024.82	26,107.29	.269	.547
1955	1.24	0.00	2,477.74	9,312.03	13,609.18	29,002.30	.182	.321
1956	0.88	0.10	2,612.05	15,990.64	12,625.97	37,005.21	.207	.432
1957	353.46	70.85	10,462.48	22,613.43	20,314.55	43,525.24	.515	.520
1958	2,488.91	417.71	15,609.80	26,463.02	30,719.23	27,187.78	.508	.973
1959	1,380.96	81.68	13,126.17	32,740.46	15,295.41	32,740.46	.858	1.000
1960	24.20	10.48	4,339.03	32,126.08	11,952.51	35,112.63	.362	.915

TABLE II

Average Sea Surface Temperatures in Degrees Centigrade for the First Half of Each Year at Scripps Pier, La Jolla

Year	Average of first six months	Year	Average of first six months
1945	15.0	1953	14.7
1946	15.4	1954	15.4
1947	15.8	1955	15.0
1948	14.8	1956	14.6
1949	15.0	1957	15.9
1950	14.8	1958	16.6
1951	15.4	1959	17.1
1952	15.1	1960	15.6

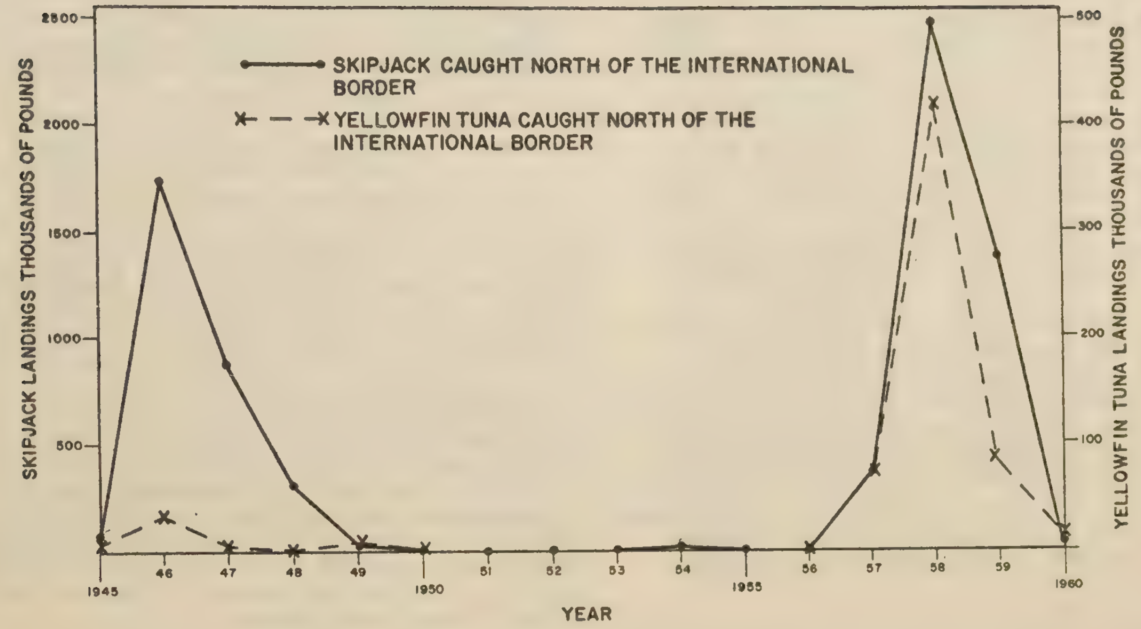

Fig. 1 California landings of skipjack and Pacific yellowfin tuna caught north of the U.S.-Mexican Boundary, 1945 to 1960.

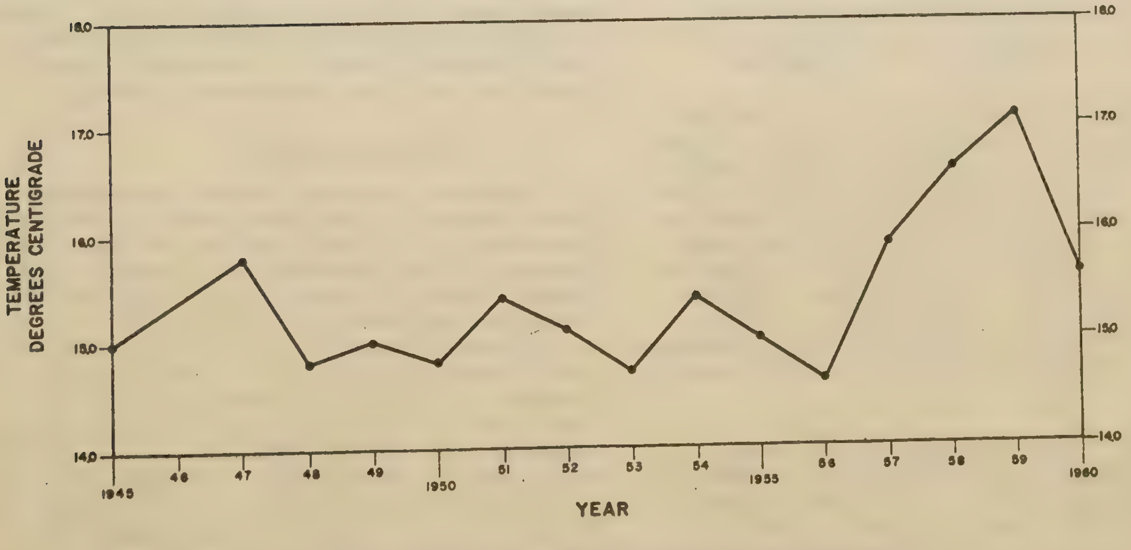

Fig. 2 Average of sea-surface temperatures during the first half of the year (January through June) collected from Scripps Pier, La Jolla, California, 1945 to 1960.

Another indicator of the local skipjack abundance is the average daily skipjack catch by anglers fishing from southern California sportfishing party boats (Table III, Fig. 3). In this instance, 1957 was the outstanding year, instead of 1958. The catch-per-angler was also above the median in 1958 and 1959. The catch in 1960 was near the median and the average temperature in 1960 was near the long-term mean. Thus, the sportcatch peaked in 1957, the local commercial catch peaked in 1958, and the highest temperatures occurred in 1959.

Most of the local skipjack and yellowfin tuna are caught offshore by purse seiners; party-boat sportcatches are made closer inshore by hook and line with live bait. If the fish are densely schooled and farther offshore, commercial catches will be good while sport catches are poor. If the fish scatter or break up into small schools and move inshore, sportcatches will be better and commercial fishing poorer.

Despite the variations described, the evidence is strong that the northern distribution of skipjack and yellowfin is a function of water temperature. The local commercial catches of both species are similar (Fig. 1); they both increased during the warm-water period, as did the party-boat catch of skipjack (Fig. 3). The northern range was extended for yellowfin tuna and equaled for skipjack.

If we plot the catches as a function of temperature for yellowfin (Fig. 4) and skipjack (Fig. 5), a large scatter exists but there is a distinct positive correlation. If the points are linked chronologically the slopes are positive between most years; however, there is a negative slope between 1946 and 1947, and between 1958 and 1959, for both species. This shows that between those years the catches and temperatures did not go in the same direction.

Although temperatures at Scripps Pier were higher in 1959 than in 1958, the widespread warming may have reached its peak in 1958 and the warm water of 1959 may have been confined to an area along the California and northern Baja California coasts. The high catches in 1946 do not seem consistent with the temperature, particularly for skipjack (Fig. 5). In 1948, the catch was still quite high, especially when one considers that 1948 was a cold year. There possibly is a lag after a good year and the catch may not drop as rapidly as does temperature. Radovich (1960 and 1961) suggested this phenomenon for California barracuda, Sphyraena argentea. Other possible reasons for such aberrancies have been discussed.

2.2 Albacore and bluefin tuna

To minimize the effect of population size we may calculate the proportion of California landings of albacore and bluefin tuna caught north of the International Border. These values represent an index of distribution and range from 1.00 in 1959 (Fig. 6), when virtually no albacore were caught south of California; to 0.00 in 1959 (Fig. 7), when no bluefin tuna were caught in California. The distributional index for bluefin tuna (Fig. 7) closely resembles the California catches of skipjack and yellowfin tuna (Fig. 1). Albacore, which move coastward from the mid-Pacific, were not distributed northward in the period around 1946, as the other three tunas were.

Possibly, then, the impetus for a northerly surge of skipjack, bluefin and yellowfin tuna may originate south of central Baja California; whereas the temperatures seaward from central Baja California to southern California may be more important in determining the latitude at which albacore approach the coasts. Both species were distributed farther north during the warm-water years.

2.3 Pacific bonito

Another scombrid whose latitudinal distribution along the coast seems to be related to sea temperature is the Pacific bonito. If we examine the average daily bonito catch of party-boat anglers in southern California (Fig. 8) we see that an upsurge took place with the onset of the warm-water period in 1957. Any changes in average catch-per-angler which may have been due to variations in temperature up to 1956 are too small to register on this scale. Therefore, the average catch-per-angler was plotted on a logarithmic scale and compared with the temperature for the years 1947 through 1960 (Fig. 9).

Several interesting things are revealed. In general there seems to be a relationship between angling success for bonito and sea temperatures. There are two aberrant years in this relationship,

TABLE III

Average Number of Pacific Bonito and Skipjack Tuna Caught per Party Boat Angler in Southern California

	Pacific Bonito			Skipjack Tuna		
Year	Number Caught	Anglers	Number per Angler	Number Caught	Anglers	Number per Angler
1947	36,496	318,192	.115	698	318,192	.00219
1948	14,519	352,578	.041	460	352,578	.00130
1949	5,372	396,424	.014	9	396,424	.00002
1950	2,354	439,270	.005	31	439,270	.00007
1951	14,475	439,825	.033	132	439,825	.00030
1952	7,646	437,241	.017	38	437,241	.00009
1953	6,321	378,897	.017	279	378,897	.00074
1954	70,078	392,181	.179	50	392,181	.00013
1955	22,409	350,112	.064	10	350,112	.00003
1956	61,404	370,144	.166	13	370,144	.00004
1957	258,520	429,801	.601	6,448	429,801	.01500
1958	422,565	407,357	1.037	491	407,357	.00121
1959	774,311	436,414	1.774	512	436,414	.00117
1960	1,199,846	522,387	2.297	378	522,387	.00072

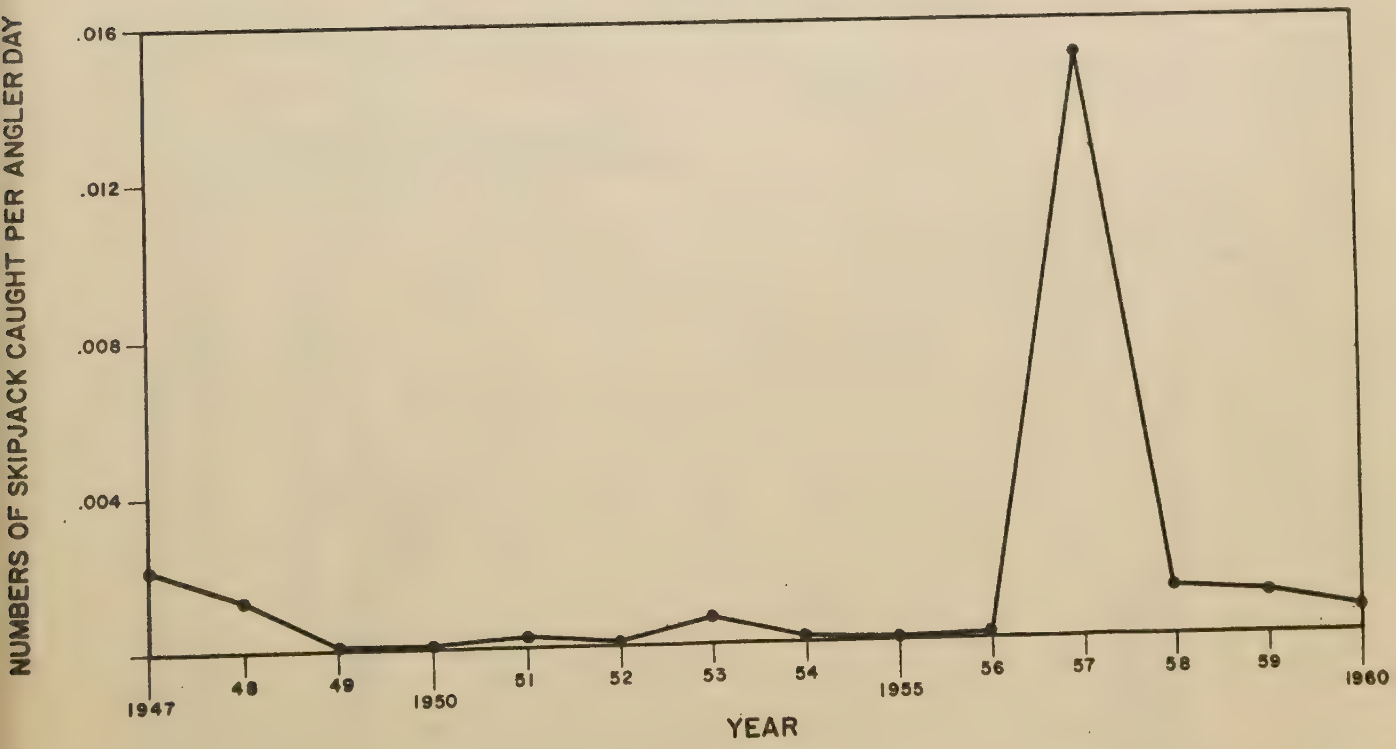

Fig. 3 Angler's average daily catch of skipjack tuna from southern California sportfishing party boats from 1947 through 1960.

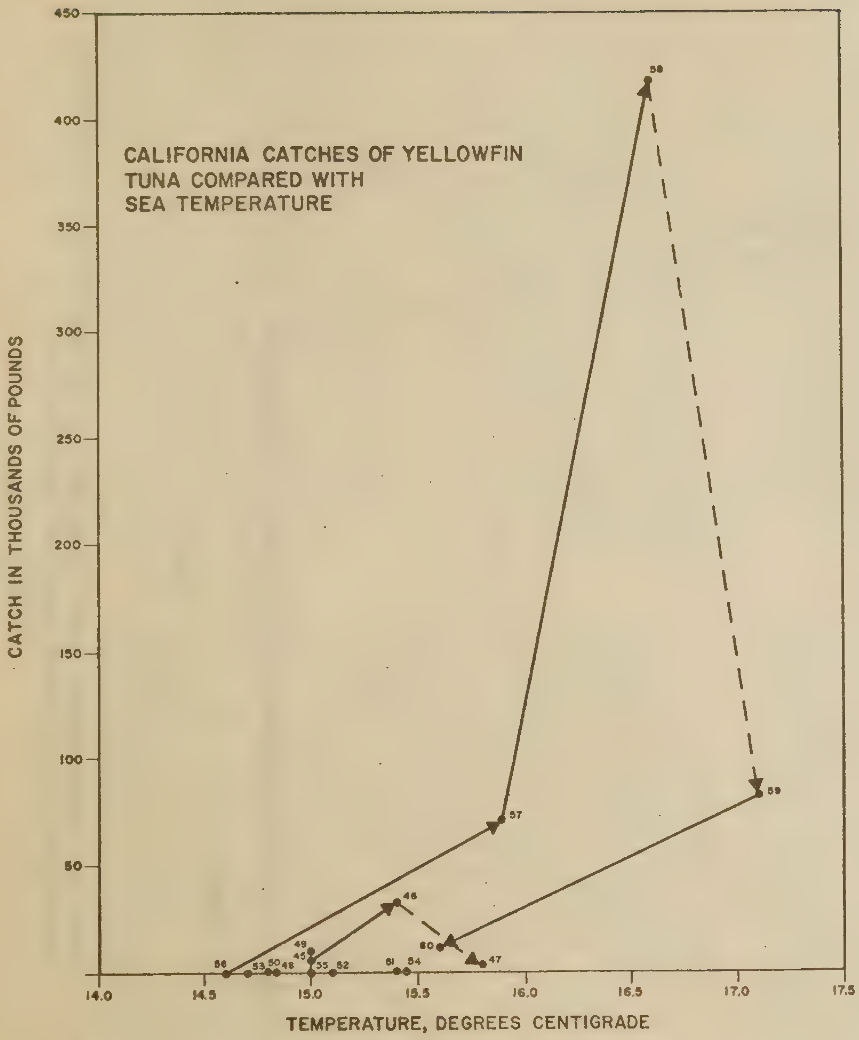

Fig. 4 California catches of Pacific yellowfin tuna related to the average of sea-surface temperatures for the first six months of each year (taken at Scripps Pier, La Jolla). Prominent years are linked chronologically. Dotted lines indicate negative slopes.

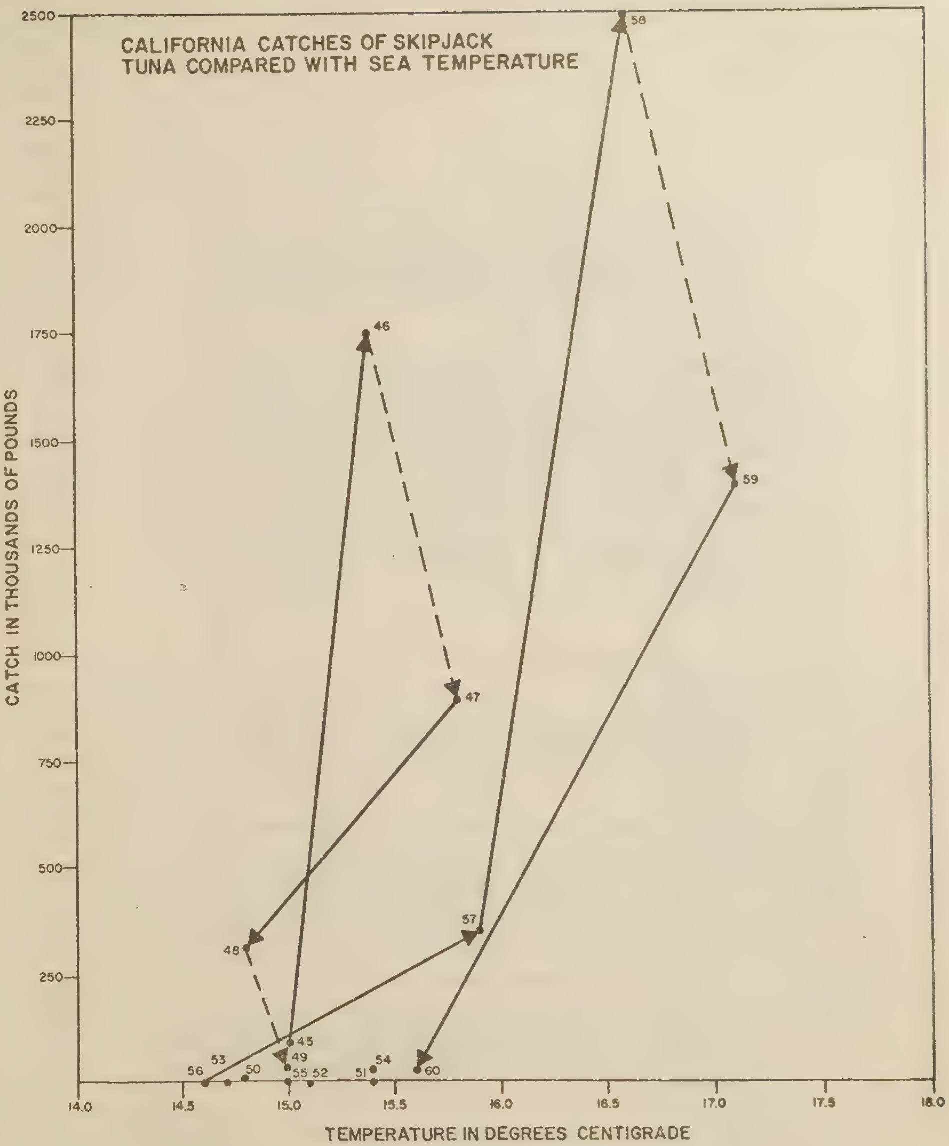

Fig. 5 California catches of skipjack tuna related to the average of sea-surface temperatures for the first six months of each year (taken at Scripps Pier, La Jolla). Prominent years are linked chronologically. Dotted lines indicate negative slopes.

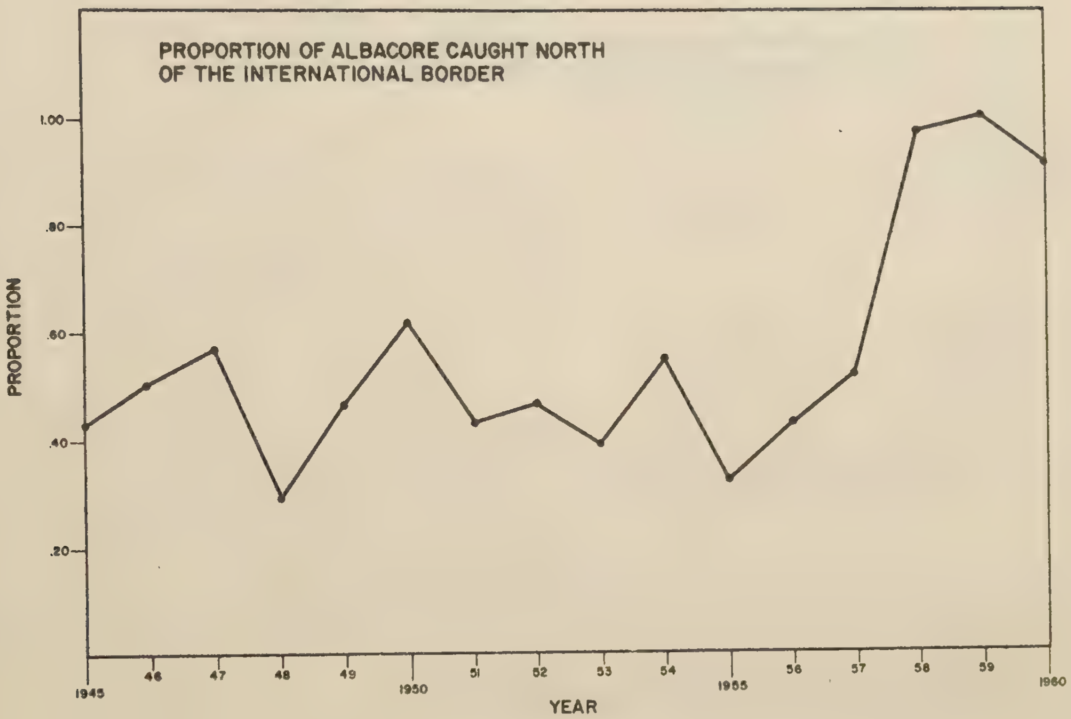

Fig. 6 Proportion of Pacific albacore landings in California caught north of the U.S.-Mexican Boundary, 1945 to 1960.

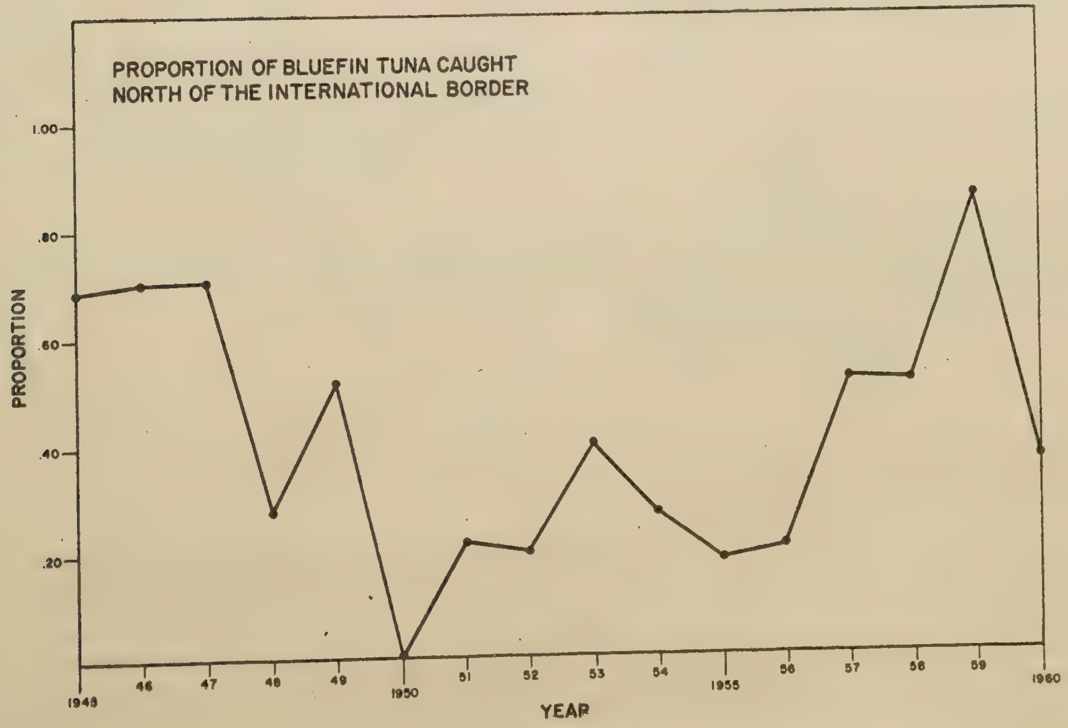

Fig. 7 Proportion of bluefin tuna landings in California caught north of the U.S.-Mexican Boundary, 1945 to 1960.

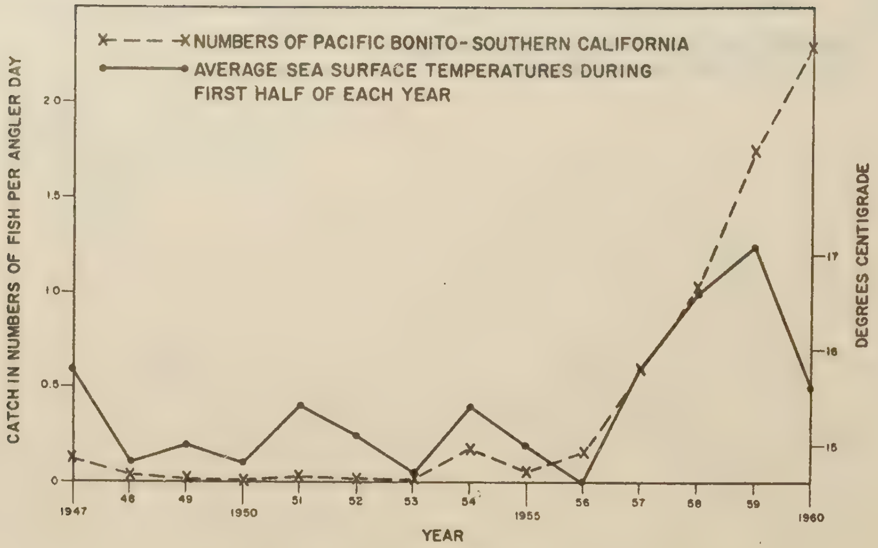

Fig. 8 Angler's average daily catch of Pacific bonito from southern California sportfishing party boats compared with the average sea-surface temperature during the first half of each year, 1947 to 1960.

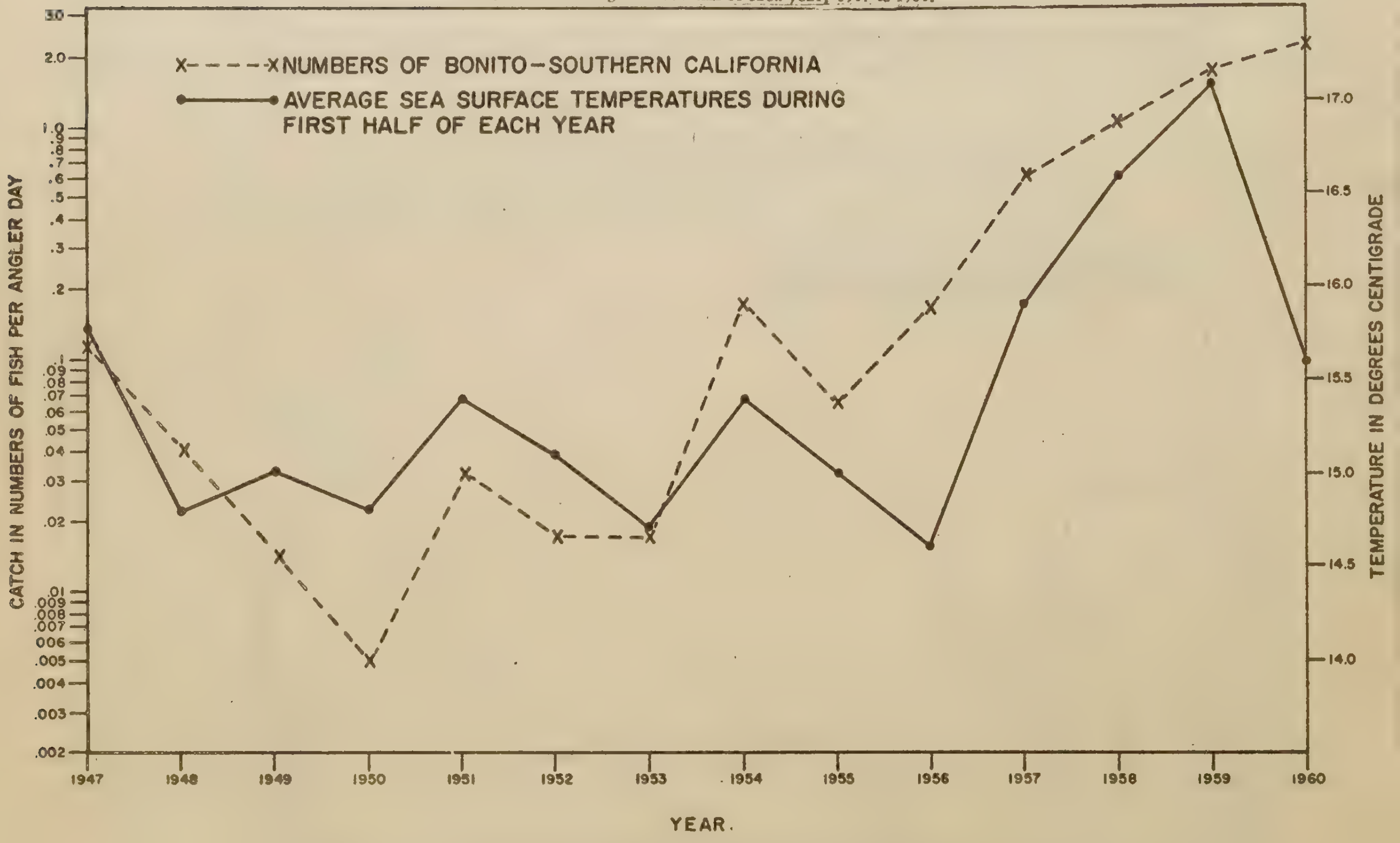

Fig. 9 Logarithmic plot of angler's average daily catch of Pacific bonito from southern California sportfishing party boats compared with the arithmetic plot of the average sea-surface temperature during the first half of each year, 1947 to 1960.

1956 and 1960. In 1956, water temperatures were quite low until June (Fig. 10). During the last half of 1956 they were approximately average. Apparently the warm period had begun quite subtly during the last half of 1956 and by 1957 water temperatures were definitely above the long-term mean.

The catch-per-angler of bonito did not amount to much until the last half of the year (Fig. 11). It is probable, then, that bonito responded rapidly to the rise in water temperatures during the last half of 1956. The discrepancy for 1956 (Fig. 9) apparently arose because the temperatures for the first six months of 1956 were low in contrast to the last half.

The other major discrepancy occurred in 1960, when the temperature dropped markedly while the catch-per-angler improved. There are known factors operating to an unknown degree which would tend to cause this. One such factor is a preference of the partyboat anglers for other game fish such as yellowtail and barracuda. When these species are plentiful, bonito are frequently avoided. Often when a boat is surrounded by an active school of bonito, the anchor is picked up and the vessel moves to another location to look for the more desirable species. On the other hand, when the more-desirable game species are scarce, bonito are sought. When yellowtail and barracuda catches dropped in 1960, bonito were pursued more vigorously. To what extent this influences catch-per-effort values is not known but I believe it is considerable.

Another factor affecting the distribution of a species is the distribution of its spawning success. In addition to moving northward into California waters during the warm years, bonito also spawned successfully in these waters. This further increased the local population.

There may be a tendency for bonito to remain in the area in which they are living unless moved by extreme temperatures or they simply may respond more rapidly to high temperatures than to low ones.

Although the average of temperatures for 1960 was slightly below the long-term mean, the 1959-60 winter temperatures were above average (Fig. 10). If extreme temperatures were needed to supply the inertia for the fish to move, they were not encountered during 1960.

When the average catch of bonito by partyboat angler is plotted against temperature (Fig. 12) an exponential curve is strongly suggested. The two points representing 1956 and 1960 are the only large deviations from the fitted exponential curve. This curve suggests variations in average water temperature below 15.5 C do not result in large variations in angling success, but above 15.5 C the average temperature becomes increasingly important.

The exponential curve,

$$Y = 1.353 \times 10^{-14} (1.2122)^{10X},$$

fits the data within the range of temperatures experienced, where Y is the number of bonito caught per angler day and X the average of sea-surface temperatures for the first six months of the year at Scripps Pier. Theoretically, an exponential curve does not describe the relationship; it merely approximates it, emperically, within limits. Actually, there must be a limit to the catch-per-effort.

If the bonito population spans the International Border and the northward distribution of the population is a function of temperature, then should temperatures along the coast increase continuously (beyond any observed values), the catch-per-effort obviously would reach a limit when the total population moved north of the Border. Another limiting factor is the sportfish daily bag limit of 10 bonito imposed by the State of California.

If we consider the possibility of even higher temperatures, we may conceive that fish would be distributed so far northward they again would become largely unavailable to the southern California sportfishery. In this case, the catch-per-angler would drop as temperatures increased. Thus, it is logical to believe that within the temperatures observed, the relationship which exists between bonito fishing success and sea temperatures is described by the left limb of a bell-shaped curve. The dome of this curve may be somewhat flattened because of the effect of the 10-fish bag limit.

2.4 Discussion of the additional relationships

If sufficient refined data were at hand, one might suspect that a bell-shaped curve would express the relationship between temperature and the local abundance of bluefin, skipjack and yellowfin tunas, provided the total population size was constant. Certainly, comparing the commercial yellowfin tuna catch with temperature (Fig. 4) suggests a similar phenomenon.

As a conclusion, we may state that evidence for the relationship of tuna distributions to sea temperature is accumulating and rapidly becoming overwhelming.

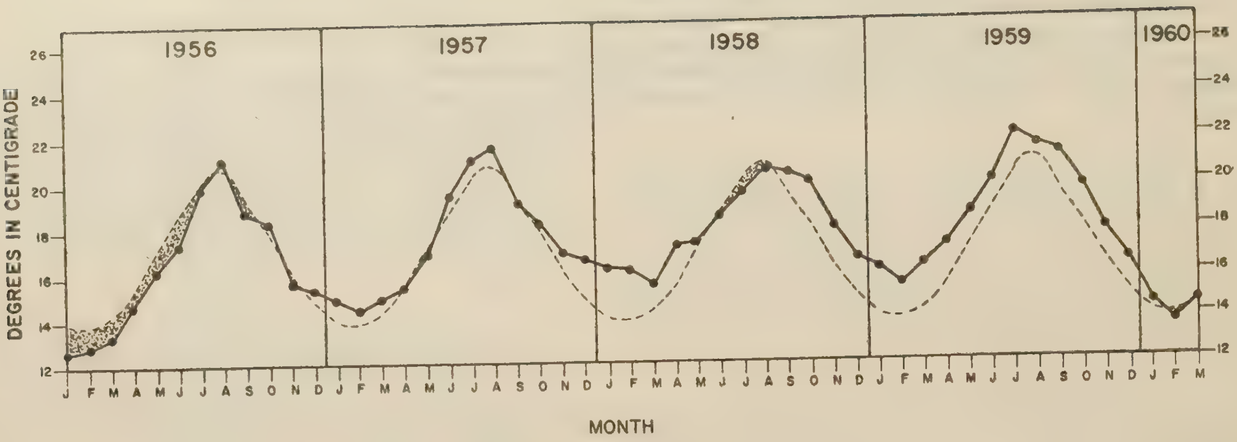

Fig. 10 Monthly deviations from the 1917 through 1955 mean of sea-surface temperatures taken at Scripps Pier. The dotted line indicates the long-term monthly mean and the solid line, the monthly average in each year. The stippled areas between the lines represent departures below the mean while the unstippled areas represent warmer than average temperatures.

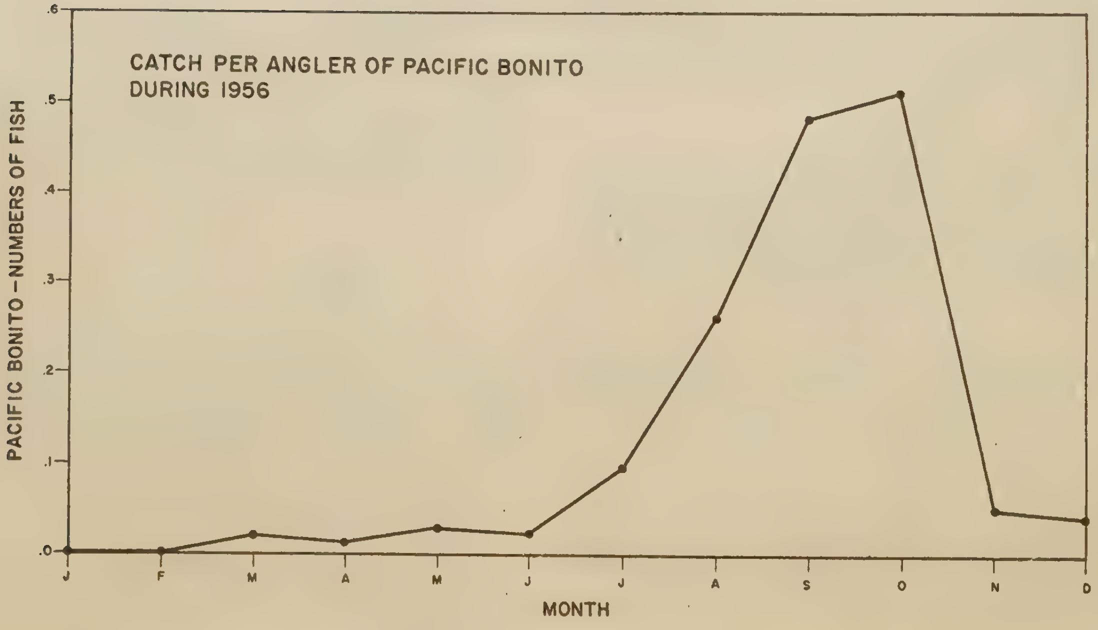

Fig. 11 Average daily catch per angler of Pacific bonito during 1956, by month, from southern California sportfishing party boats.

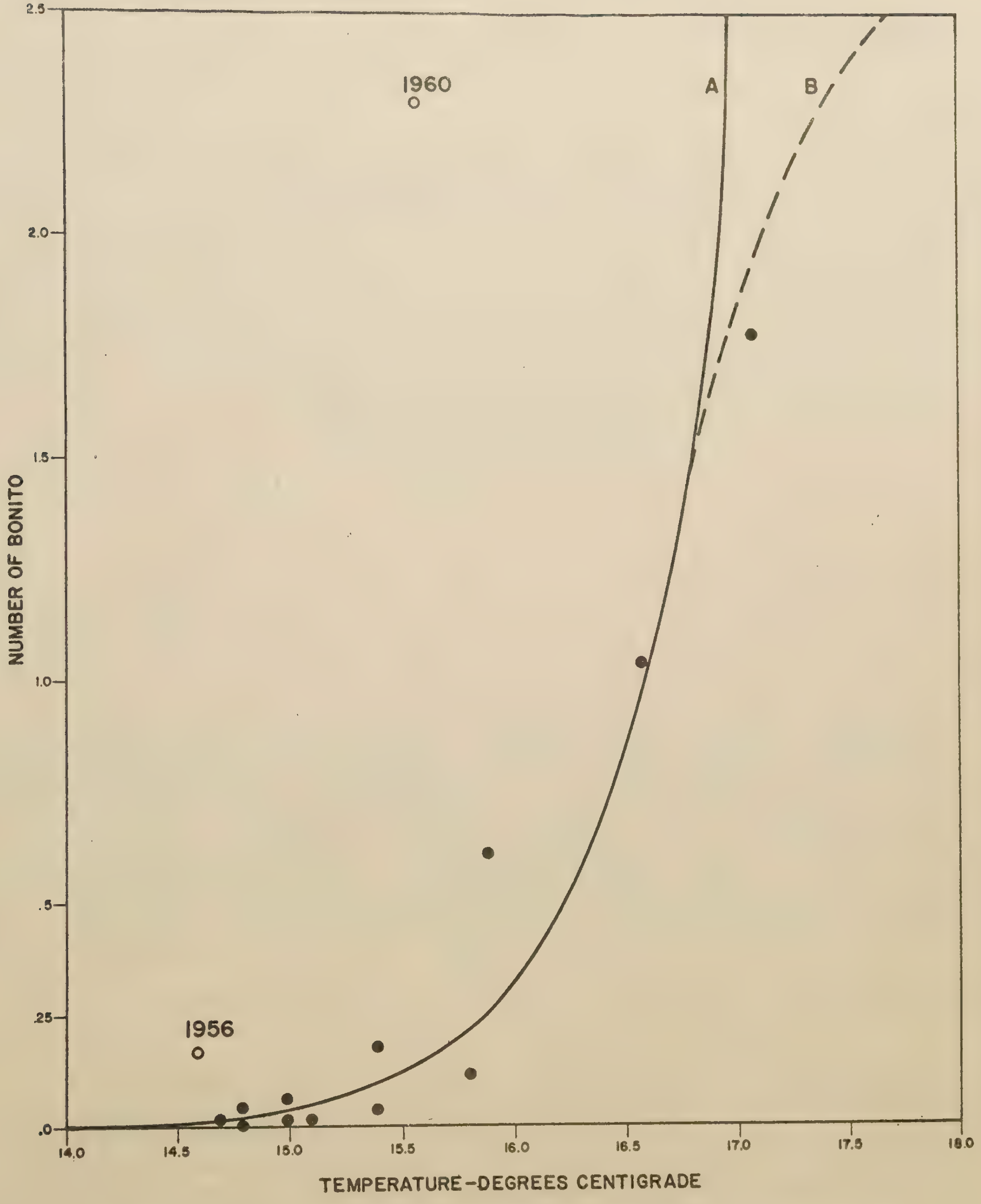

Fig. 12 Southern California average party boat angler's daily catch of bonito compared with the January to June average surface temperature at Scripps Pier from 1947 through 1960. The solid line (A) is the exponential curve $Y=1.353\times10^{-14}(1.2122)^{10X}$. The dotted line (B) indicates a theoretical relationship which has an upper limit. The largest departures from either curve occurred in 1956 and 1960 and are indicated by open circles.

Experience Paper No. 28

DISTRIBUTION OF TUNA SPECIES IN THE OCEANIC NORTHWEST ATLANTIC

By

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Abstract

Explorations of the oceanic Northwest Atlantic by the exploratory fishing vessel Delaware during the years 1957 to 1960, using sub-surface longline fishing gear, indicates that bluefin tuna, *Thunnus thynnus*, are abundant along the northern zone of the Gulf Stream area in winter and spring. Species dominance in this area changes from bluefin tuna to yellowfin tuna, *Thunnus albacares*, during the summer and early autumn. Limited catches of albacore, *Thunnus alalunga*, were taken over a wide area of the oceanic Northwest Atlantic. Bigeye tuna, *Thunnus obesus*, were occasionally taken, and usually in association with bluefin tuna. Other tuna species of blackfin tuna, *Thunnus atlanticus* and skipjack tuna, *Euthynnus pelamis*, were recorded.

Catch per unit effort ranged from zero to 20.8 fish, or 1,431 kg per 100 hooks for bluefin tuna and 14.1 fish, or 568 kg per 100 hooks for yellowfin tuna.

Areas of tuna abundance show a general relationship to the Gulf Stream area. This area is analogous to the Kuroshio Current of the Northwest Pacific, and bluefin tuna in the Gulf Stream show a similarity in migration pattern to bluefin tuna (black tuna, *T. orientalis*) of the Northwest Pacific. The occurrence of yellowfin tuna in the higher latitudes of the Gulf Stream would suggest that this water mass is an extension of the environment found in the Atlantic North Equatorial Current.

REPARTITION GEOGRAPHIQUE DES DIVERSES ESPECES DE THONS DANS L'ATLANTIQUE NORD-OUEST

Résumé

Les campagnes exploratrices de pêche effectuées dans l'Atlantique Nord-Ouest par le "Delaware" de 1957 à 1960 au moyen de palangres calées en profondeur ont révélé la présence d'un grand nombre de thons rouges (Thunnus thynnus) dans la zone septentrionale du Gulf Stream en hiver et au printemps. En été et au début de l'automne, l'espèce dominante devient le thon à nageoires jaunes (Thunnus albacares). Des germons (Thunnus alalunga) ont été pris, en petits nombres, dans une zone étendue de l'Atlantique Nord-Ouest, ainsi que, de temps à autre, des thons obèses (Thunnus obesus), généralement en même temps que des thons rouges. Les captures ont porté également sur deux autres espèces de thons: le "thon noir" (Thunnus atlanticus) et la bonite à ventre rayé (Euthynnus pelamis).

Les captures par unité d'effort ont varié entre zéro et 20, 8 poissons, ou 1 431 kg, pour 100 hameçons, en ce qui concerne le thon rouge, et 14, 1 poissons, ou 568 kg, pour 100 hameçons, en ce qui concerne le thon à nageoires jaunes.

L'abondance des thons est dans l'ensemble en rapport avec le parcours du Gulf Stream. La zone du Gulf Stream présente des analogies avec celle du Kuro-Shio, dans le Pacifique Nord-Ouest, le thon rouge présent dans la première manifestant un schéma migrationnel semblable à celui du thon rouge (Thunnus orientalis) du Pacifique Nord-Ouest. La présence de thons à nageoires jaunes dans les latitudes supérieures du Gulf Stream permet de supposer que cette masse d'eau constitue un prolongement du milieu représenté par le courant nord-équatorial atlantique.

DISTRIBUCION DE LAS ESPECIES DE ATUNES EN EL NOROESTE DEL OCEANO ATLANTICO

Extracto

Las exploraciones de la parte oceánica del Atlántico noroeste, efectuadas por el barco de investigación pesquera "Delaware" durante los años 1957 y 1960, utilizando aparejos de palangre subsuperficiales, indican que el atún de aleta azul Thunnus thynnus abunda a lo largo de la zona septentrional de la Corriente del Golfo (Gulf Stream), en invierno y en primavera. La dominancia de especies en dicha zona varía del atún de aleta azul al de aleta amarilla Thunnus albacares, durante el verano y principios del otoño. Las capturas de albacora Thunnus alalunga en una amplia zona del noroeste del Atlántico fueron limitadas. En algunos casos se capturó atún patudo Thunnus obesus, generalmente unido a atún de aleta azul. Se registraron también algunas otras especies de atunes, como el de aleta negra, Thunnus atlanticus, y el barrilete, Euthynnus pelamis. La captura por unidad de esfuerzo osciló entre ser nula y 20, 8 ejemplares con 1.431 Kg. por

cada 100 anzuelos para el atún de aleta azul, y 14,1 individuos o 568 Kg. por 100 anzuelos, para el de aleta amarilla.

Las áreas de abundancia de atún muestran una correspondencia general con las de la zona de la Corriente de Golfo. Este área es análoga a la de la Corriente del Kuro-Sivo del noroeste del Pacífico, y el atún de aleta azul de la Corriente del Golfo muestra una analogía en las características de migración con el atún de aleta azul (atún negro, _T. orientalis_) del noroeste del Pacífico. La presencia de atún de aleta amarilla en las latitudes superiores de la Corriente del Golfo sugeriría que esta masa de agua constituye una extensión del medio ambiente hallado en la Corriente Ecuatorial del norte del Atlántico.

1 INTRODUCTION

Knowledge of the distribution and abundance of tuna species in the oceanic areas of the Northwest Atlantic was non-existent only a decade ago. Between the edge of the North American continental shelf, from off Cape Hatteras to the Grand Bank, and to north of the island of Bermuda, there were but three substantiated records of tuna captures. Yet, on the continental shelf, adjacent to this area, there exists a seasonal commercial and sport fishery for bluefin tuna, Thunnus thynnus (Linnaeus) (Bigelow and Schroeder 1953). The fishery resources of the continental shelf have been under intensive biological research for many years, yet research concerning the fishery resources of the oceanic Northwest Atlantic has been neglected.

It has been evident for many years that knowledge was lacking on the existence of fishery resources in the Gulf Stream area. In 1957 the United States Fish and Wildlife Service's Bureau of Commercial Fisheries, through its North Atlantic Fisheries Exploration Base, Boston, Massachusetts, began limited explorations in the oceanic Northwest Atlantic. The objective of the exploratory cruises were to test the hypothesis that species of bluefin tuna were present in or near the environment of the Gulf Stream during the winter and spring seasons. If tuna were found in this area, studies would be made to determine the seasonal distribution and availability of the major species to commercial fishing gear. During the period from March 1957 through May 1960 a total of eight exploratory cruises were conducted intermittently by the 148-foot exploratory fishing vessel Delaware to examine the pelagic fishery resources of the oceanic area (Fig. 1).

A total of 111 stations were fished during the period 1957 to 1960, using a total of 5,674 ten-hook "baskets", or sections, of Japanese tuna longline gear. The amount of gear used at each fishing station ranged from 30 to 80 sections, with 60 sections being the target number. Atlantic herring (frozen), Clupea harengus harengus, Linnaeus, were used as bait, this species being available in the coastal areas, eastward from about longitude 73°W. Though explorations were conducted intermittently over an extended period of time, the results have provided the limited amount of knowledge now available concerning the distribution and abundance of tuna in the oceanic Northwest Atlantic.

Seven species of the family Scombridae were taken during the explorations;

> bluefin tuna, Thunnus thynnus (Linnaeus), yellowfin tuna, Thunnus albacares (Bonnaterre), albacore, Thunnus alalunga (Bonnaterre), bigeye tuna, Thunnus obesus (Lowe), blackfin tuna Thunnus atlanticus (Lesson) and skipjack tuna, Euthynnus pelamis (Linnaeus).

Of these, the first three constitute the major species available to the longline gear. In addition, increased knowledge concerning the distribution of such pelagic species as the lancetfish (Gibbs 1960), wahoo (Rathjen and Squire 1960) swordfish and marlin (Squire 1962) was gained. Information on many other species of pelagic fish and sharks was also obtained.

2 REVIEW OF KNOWLEDGE TO 1957

Prior to the beginning of exploratory research in early 1957, a reference check revealed that only a limited amount of information was available on the species common to the oceanic area. It was impossible, therefore, to make any conclusions regarding the distribution and availability of tuna.

Records concerning tuna in the oceanic area consisted of an occasional trolling capture by oceanographic research vessels from the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, during the period 1949 to 1956. Ten specimens of tuna, which composed four species, were recorded from these cruises and published by Mather (1954), Mather and Schuck (1952), Mather and Day (1954), and Mather and Gibbs (1957). Records were for the following species:

yellowfin tuna 5 specimens Thunnus albacares	1. 38° 21' N. Lat. -71° 37' W. Long. R/V Caryn, August 1949
	2. 37° 22' N. Lat. -71° 05' W. Long. R/V Atlantis, August 1953
	3. 39° 22' N. Lat. -72° 22' W. Long. R/V Atlantis, October 1953
	4. 38° 18' N. Lat. -70° 29' W. Long. R/V Atlantis November 1953

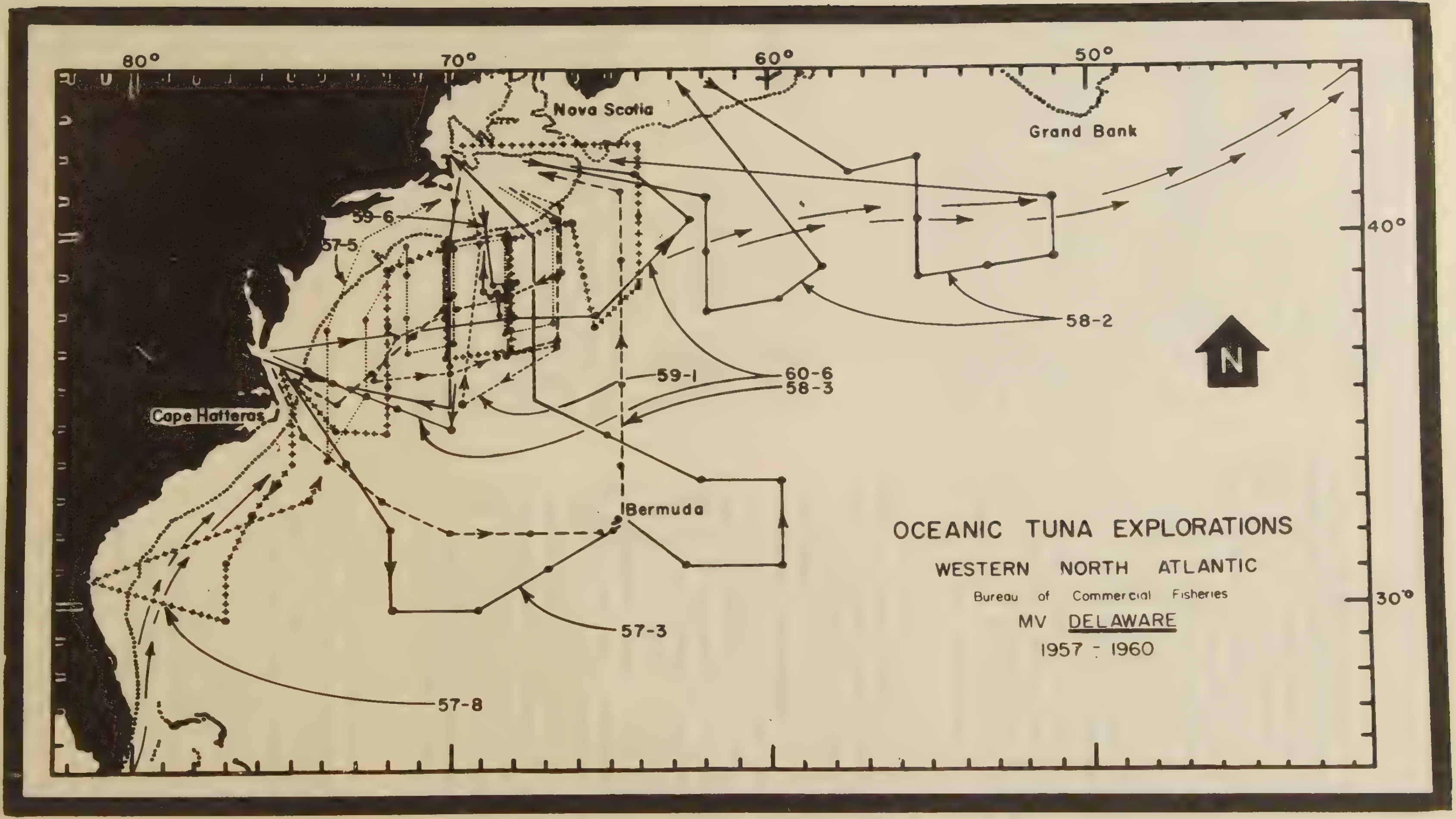
OCEANIC TUNA EXPLORATIONS
WESTERN NORTH ATLANTIC
Bureau of Commercial Fisheries
MV DELAWARE
1957 - 1960
N
80°
70°
60°
50°
40°
30°
Nova Scotia
Grand Bank
Cape Hatteras
Bermuda
59-6
57-5
58-2
59-1
60-6
58-3
57-3
57-8

Fig. 1 Diagram of the oceanic area explored and the fishing patterns used in the determination of the abundance and distributions of tuna species.

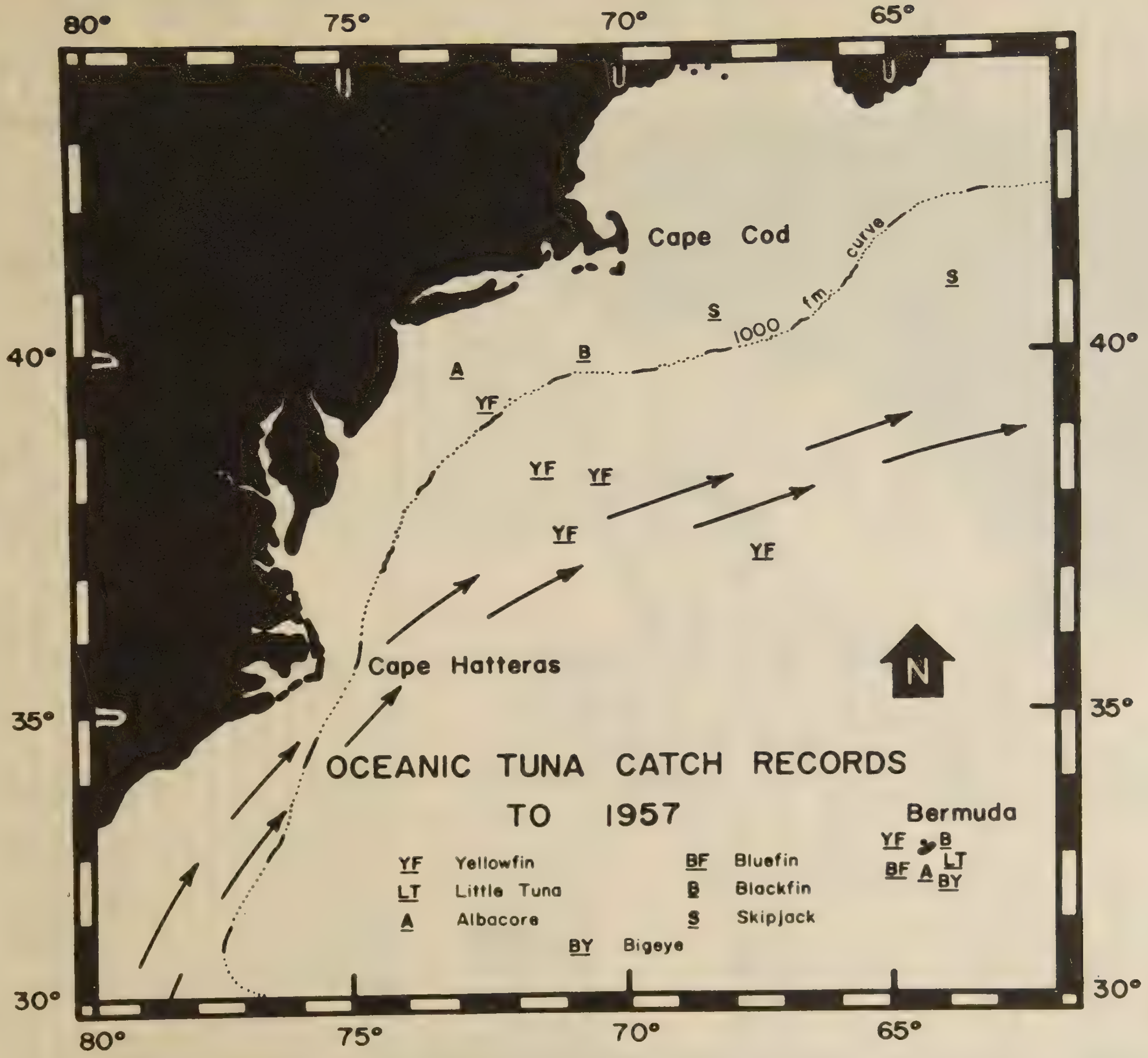
OCEANIC TUNA CATCH RECORDS
TO 1957
Cape Cod
Cape Hatteras
Bermuda
1000 fm. curve
N
YF Yellowfin
LT Little Tuna
A Albacore
BF Bluefin
B Blackfin
S Skipjack
BY Bigeye
80°
75°
70°
65°
40°
35°
30°

Fig. 2 Positions of recorded captures of tuna in the oceanic region of the Northwestern Atlantic to 1956

		5. 37° 02' N. Lat. -67° 34' W. Long. R/V *Atlantis*, September 1954
albacore *Thunnus alalunga*	1 specimen	1. 39° 45' N. Lat. -73° 00' W. Long. R/V *Bear* September 1956
skipjack tuna *Euthynnus pelamis*	2 specimens	1. 41° 06' N. Lat. -64° 12' W. Long. (report of L. R. Day) July, 1955
		2. 40° 40' N. Lat. -68° 28' W. Long. R/V *Bear*, September 1956
blackfin tuna *Thunnus atlanticus*	2 specimens	1. 32° 21' N. Lat. -64° 37' W. Long. R/V *Atlantis* June 1948
		2. 40° 04' N. Lat. -70° 42' W. Long. R/V *Caryn* October 1948

In 1956 Mowbray published the results of limited exploratory longlining near Bermuda, reporting that four species of tuna were taken: bluefin, yellowfin, albacore and little tuna, *Euthynnus alletteratus* (Rafinesque).

3 EXPLORATORY RESULTS

Intermittent explorations during the four-year period covered all seasons of the year. The strategy of exploration was to cover a broad oceanic area, using a "ladder" search technique where applicable. Stations were plotted in advance, in most cases from 145 to 200 km apart. Eight oceanic cruises were completed by the *Delaware* and were identified as: Cruises 57-3, 57-5, 57-8, 58-2, 58-3, 59-1, 59-6 and 60-6. Maximum exploratory effort was expended during the spring season - 37.8 percent (March, April and May); summer season - 32.5 percent (June, July and August); fall season - 19.8 percent (September, October and November) and the winter season - 9.9 percent (December, January and February). Cruise objectives were to investigate areas where oceanographic data indicated the possibility of tuna, or to conduct more detailed investigations of areas where tuna concentrations had been observed on earlier cruises.

In tabulated results of exploratory fishing by the *Delaware* (Appendix A) catches are shown in two forms: (1) the number of fish per 100 hooks and (2) the kilograms of fish per 100 hooks. Due to the multi-species catch composition on many stations and the wide weight differentials occurring within a species, bluefin tuna in particular, it is believed that this type of recording system would better describe the results and provide information for economic evaluation.

Catch results ranged from a zero catch per 100 hooks to 20.3 fish per 100 hooks and a weight of 1,431.8 kg per 100 hooks.

4 OBSERVED SEASONAL DISTRIBUTION OF SPECIES

Explorations indicate that the oceanic area, from the Gulf Stream axis to the continental shelf off northeastern North America, experiences a pronounced shift in species dominance from bluefin tuna in the winter and spring to yellowfin tuna during the seasons of summer and early fall.

Figures 3 to 7 show the distribution of the dominant species at each station, by season, to illustrate the gross changes in species distribution for the oceanic area. Dominant species are recorded for each station yielding a catch of tuna, regardless of the number. Material in Appendix B is included to show the observed distribution and catch per unit effort for bluefin, yellowfin and albacore tuna during all seasons.

Bluefin tuna

Bluefin tuna were found to be abundant in the area north of the axis of the Gulf Stream to the continental shelf during the winter and spring seasons. Winter explorations accounted for only 9.9 percent of the total effort and were restricted to one cruise (59-1) during the months of January and February. This cruise covered only the Gulf Stream area south of Cape Cod. Therefore, information on the extent of distribution eastward to the Grand Bank during the winter season is not known. The maximum catch rate for bluefin tuna at any one station during the winter period was 5.55 fish, taken on 21 January, 1959, at station 89. 1/

The distribution pattern during the spring season appears to be similar to that observed

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1/ See Appendix A for station data

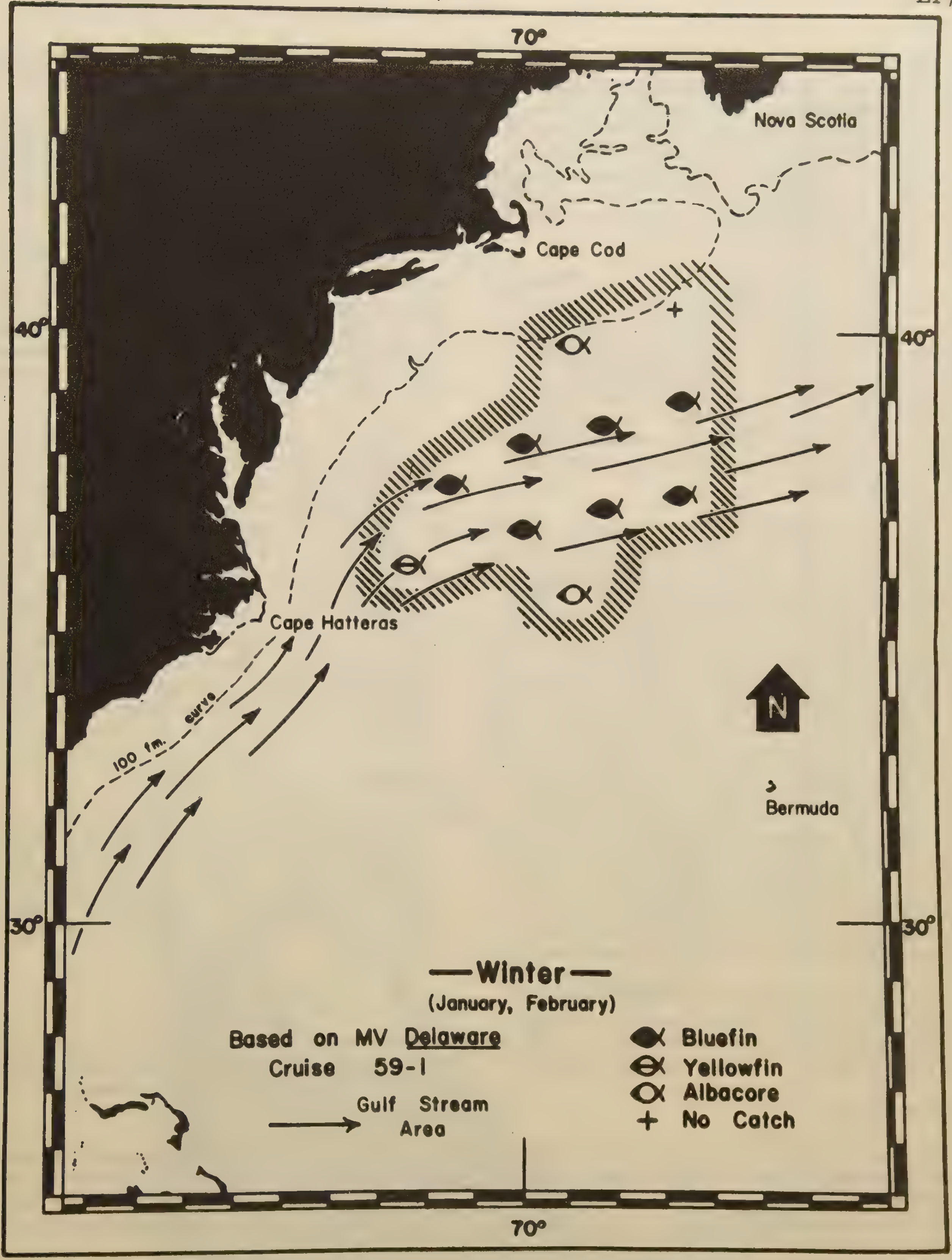

70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm. curve
N
Bermuda
30°
30°
—Winter—
(January, February)
Based on MV Delaware
Cruise 59-1
Gulf Stream
Area
Bluefin
Yellowfin
Albacore
+ No Catch
70°

Fig. 3 Distribution of dominant tuna species, winter season (Jan. Feb.), in the oceanic Northwest Atlantic

during the winter for the areas explored during both seasons. Bluefin tuna were taken at the easternmost stations, both in the area of the Gulf Stream southwest of the Grand Bank and at a station 240 kilometers northeast of Bermuda. The oceanic area east of Georges Bank and south of Nova Scotia yielded a maximum catch of bluefin for any one station of 13.16 fish, on 5 May 1958, at station 63.

The area near the intersection of 70°W longitude and the Gulf Stream frontal zone was found to be consistently most productive during the spring season, yielding the maximum catch of bluefin tuna at any one station (station 101) on 24 May, 1959; 20.8 fish, or 1,431 kg per 100 hooks at 38° 37' N, 68° 24' W. This general area should be commercially productive for bluefin tuna, using longline gear during the winter and spring months.

During late spring and early summer, bluefin tuna migrate from the oceanic areas south of the continental shelf and become abundant on the continental shelf from the general area of 37°N, east to Newfoundland. Indications are that a portion of the offshore spring population migrates to the continental shelf area of northeastern North America, but tagging results (Mather 1960) would indicate that an eastward migration could be possible. The pattern of migration from the area near the Gulf Stream axis to the inshore areas is not known. Concentrations of bluefin tuna during the late spring and early summer were observed in areas closer to the continental shelf east of longitude 68° W and at a station due east of Georges Bank. Experimental fishing by the converted trawler Golden Eagle in mid-June 1959 found concentrations of bluefin in higher latitudes closer to the continental slope than did the Delaware during cruise 59-6 in late May 1959.

Observations during mid-summer and early fall indicate bluefin tuna are uncommon in the oceanic area, having been replaced as the dominant species in this area by yellowfin tuna.

Yellowfin tuna

Explorations during the winter and spring in the area south of the Gulf Stream resulted in scattered yellowfin tuna catches over a large area. But in the summer and fall, yellowfin tuna were found to be abundant in the oceanic areas north of the Gulf Stream axis. The maximum yield at any one station during the summer season in this area was 5.0 fish on 14 July 1958, at station 71. During the fall season the maximum catch rate was 8.5 fish on 3 October 1957 at station 43.

The occurrence of yellowfin tuna in the northern latitudes and observations of yellowfin tuna catch rates on cruises in 1957, 1958 and 1959 resulted in a hypothesis on the pattern of movement of this species into the northern latitudes during late spring. The zone of concentration appeared to be near the Gulf Stream axis off Cape Hatteras. This hypothesis was partially substantiated on 23 April 1960 at 36° 07' N, 73° 25' W, when the maximum yield of 14.1 fish, or 587 kg per 100 hooks was attained in the Gulf Stream, east of Cape Hatteras (station 106).

Since only a small percentage of exploratory fishing was conducted during the late summer and fall, and none in early winter (December), the succession from yellowfin tuna to bluefin tuna in the oceanic area south of northeastern North America was not determined. A recent report by Mather and Bartlett (1962) on explorations by the R/V Crawford suggests that by mid-November yellowfin tuna are uncommon to latitudes between the area north of the Gulf Stream axis and the continental slope. Bluefin tuna were found by Mather and Bartlett to be once again the dominant species along the continental slope from 71°W to 66°W.

Albacore

Explorations have not revealed any specific migratory or distribution pattern for albacore, yet it appears to be widely distributed in areas common to both yellowfin tuna and bluefin tuna. The maximum yield was 2.0 fish, or 49 kg per 100 hooks on 4 October 1957, at 38° 12' N, 70° 00' W.

Other Tuna Species

Other species such as bigeye tuna and skipjack tuna were taken in such small quantities that little can be said of their distribution and abundance.

Bigeye tuna were taken generally in the same areas as bluefin tuna. This relationship has been recorded for the summer sport fishery for tuna and billfish, off the coast of Maryland, by Mather and Gibbs (1958).

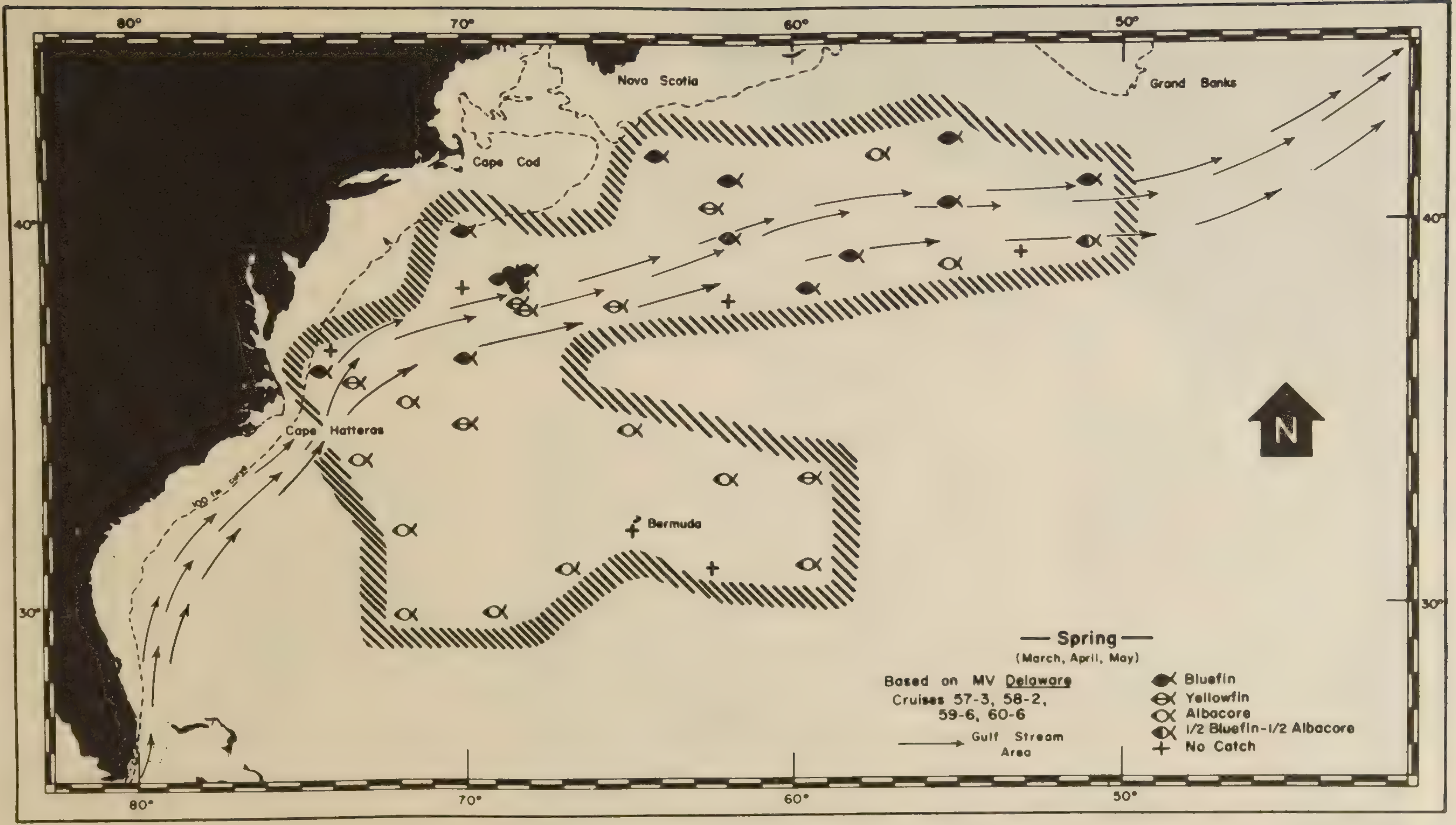

80°
70°
60°
50°
40°
30°
Nova Scotia
Grand Banks
Cape Cod
Cape Hatteras
100 fm. curve
Bermuda
N
— Spring —
(March, April, May)
Based on MV Delaware
Cruises 57-3, 58-2, 59-6, 60-6
Gulf Stream Area
Bluefin
Yellowfin
Albacore
1/2 Bluefin-1/2 Albacore
No Catch

Fig. 4 Distribution of dominant tuna species, spring season (Mar. Apr. May) in the oceanic Northwest Atlantic

5 SUMMARY AND DISCUSSION

During the period 1957 to 1960 eight exploratory cruises were conducted to determine tuna species distribution and abundance in the oceanic areas adjacent to the continental shelf, from off northeastern North America to east of the island of Bermuda. The major exploratory fishing effort was directed to investigation of tuna resources in relation to the Gulf Stream, the major oceanic current system of the Northwest Atlantic. Results indicate that six species of tuna are common to this area, and that bluefin tuna and yellowfin tuna are the dominant species. The former appears to be dominant during the winter and spring and the latter during summer and early fall.

Limited information was obtained on the distribution of other pelagic species such as albacore and bigeye tuna.

Catch rates ranged from zero to 20.8 fish and 1,431 kg per 100 hooks for bluefin tuna, and 14.1 fish and 587 kg per 100 hooks for yellowfin tuna. The strategy of exploration was to sample a large geographical area by arranging stations at least 145 to 200 km apart. The objective was to determine the gross distribution picture, rather than to attempt fishing in any one location where larger catches were possible. Only cruise 59-6 deviated from this objective. This location was preselected as one that should yield catches of bluefin tuna during the spring season. Even in this area the Delaware ranged some distance from the initial fishing location to better define the geographic distribution relationships of bluefin tuna and yellowfin tuna.

Results of exploratory fishing, coupled with observations on water temperature, indicate that water temperature is one measure of the environment that appears to be of importance in determining species distribution along the north frontal area of the Gulf Stream. Analysis of water temperature changes at the surface and at an estimated fishing depth of 52.7 m, in relation to the changes in species distribution, is discussed in other papers.

The major current system in the oceanic Northwest Atlantic is the Gulf Stream. This current is analogous to the Kuroshio of the Northwest Pacific. In these two areas there exist certain similarities in tuna distribution. Bluefin tuna or black tuna, T. orientalis are known to migrate north along the Japanese coast during the spring and summer, maintaining themselves in the cooler waters of the coastal front. This pattern is similar to the migratory pattern of the western Atlantic bluefin tuna, allowing for differences in the geographic relationship of the two areas (island vs. mainland) and their effect upon the ocean currents.

Environmental characteristics of the Gulf Stream area, from the continental shelf off northeastern North America seaward, are within an optimum range for yellowfin tuna during the summer and early fall. Temperatures are high (to 26.6°C) during the summer and early fall, and oceanographic characteristics of the area (boundary area, convergences, eddy formation) are conducive to concentrations of tuna. Yellowfin tuna are commonly thought of as inhabitants of equatorial waters, being the subject of extensive commercial fishing in latitudes of 0° to 20° in the northern hemisphere. Explorations indicate that this species occurs in abundance to latitudes of 39°N during the summer in the general area of the Gulf Stream. This area should be considered to be an extension of the environment of the North Equatorial Current, even though the current pattern of this environment is about 160° from the flow pattern at latitude 20°N. In limited exploratory work, yellowfin tuna were found in abundance near the axis of the Gulf Stream northeast of Cape Hatteras in the late spring. It is possible that this is their general northward migratory route.

Albacore are fished in the Northwest Pacific from the Japanese Islands to the mid-Pacific area during the winter, within the latitudes 22° N to 42° N. During the summer the fishing area shifts northward to latitudes of 22° N to 50°N, showing in both seasons a general relationship to the Kuroshio Current. In the summer a commercial fishery exists for albacore off the coast of southwestern Europe. This fishery is similar to the summer and early fall albacore fishery of the eastern North Pacific. If an analogous general distribution pattern exists in the North Atlantic compared to the Northwest Pacific, we might expect albacore to be found in abundance, eastward of the area of exploration (60°W) and closer to the mid-Atlantic, near the Gulf Stream.

The exploratory investigation described in this paper, as most others in the oceanic area, lack the one feature that would make for easier correlation of fish distribution to environment - that is instantaneous sampling of fish and

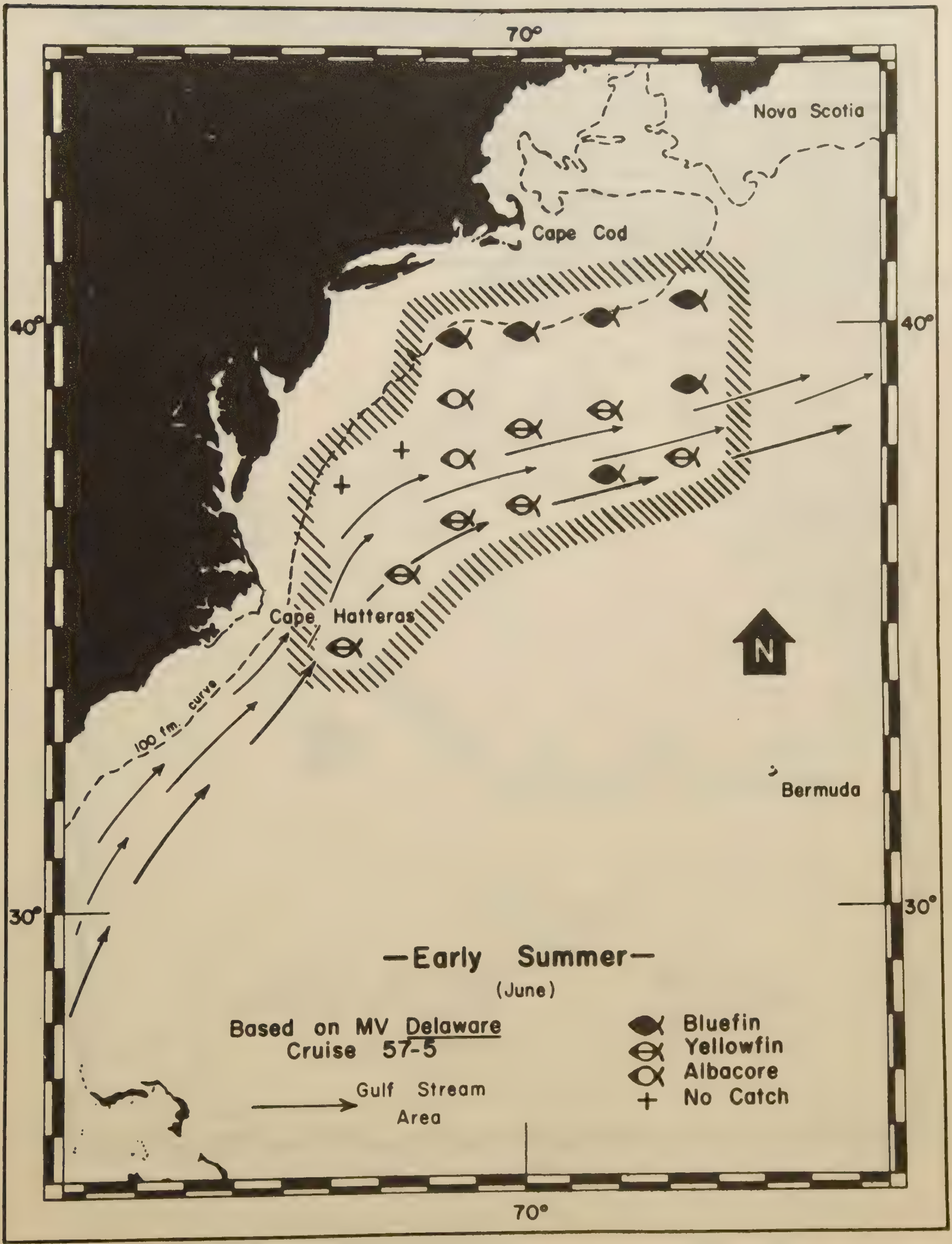

70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
N
100 fm. curve
Bermuda
30°
30°
—Early Summer—
(June)
Based on MV Delaware
Cruise 57-5
Gulf Stream
Area
Bluefin
Yellowfin
Albacore
No Catch
70°

Fig. 5 Distribution of dominant tuna species, early summer (June), in the oceanic Northwest Atlantic

associated environmental data over a large geographical area. One research vessel surveying an area of 900,000 square kilometers cannot hope to attain a detailed measure of distribution and abundance in relation to certain environmental factors without the capability of obtaining simultaneous observations at several locations. Therefore, we may only generally define the gross features of the distribution and abundance of tuna species in the area described. The results of the exploration should encourage additional interest in the development of the resources of the Gulf Stream area.

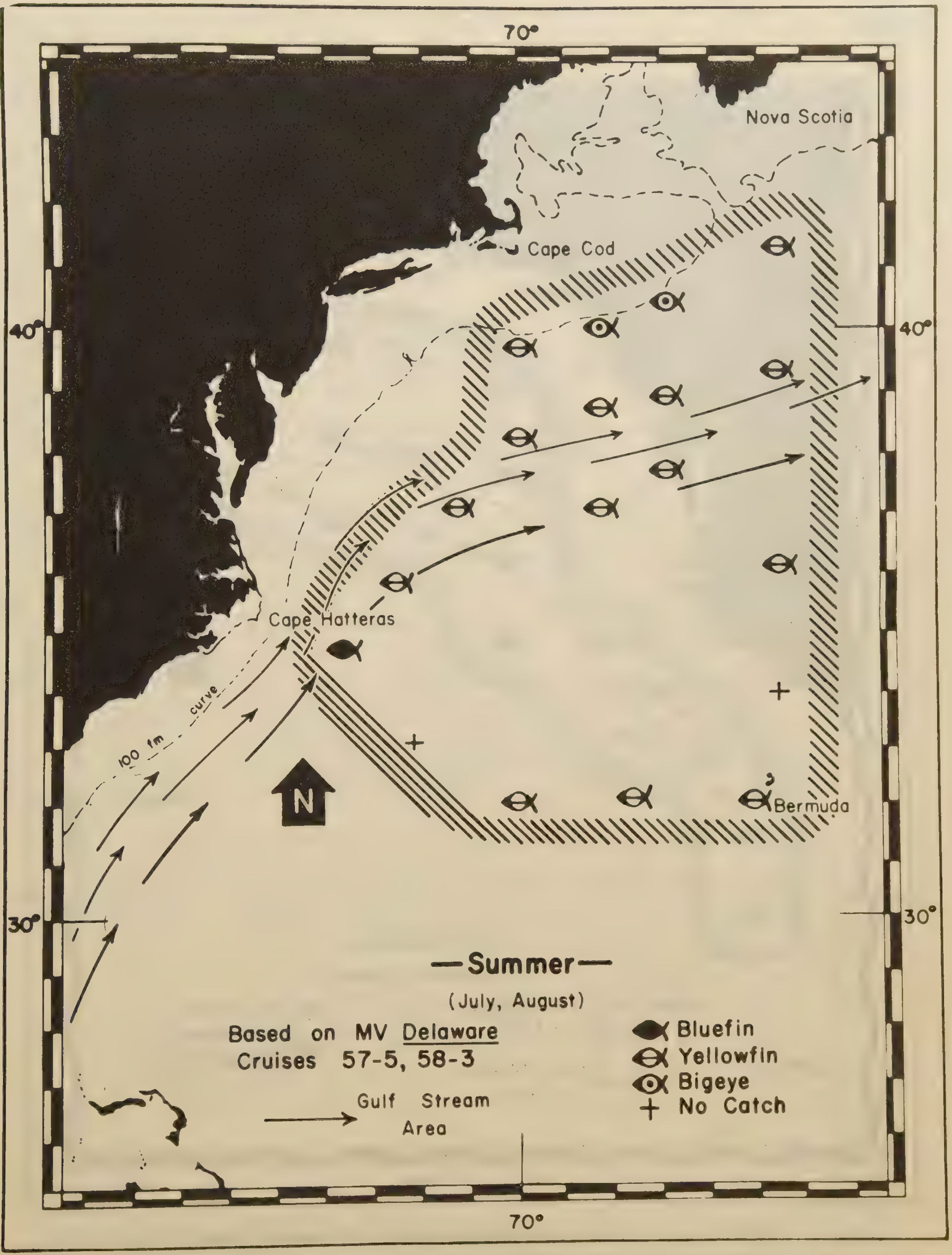

70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm curve
N
Bermuda
30°
30°
—Summer—
(July, August)
Based on MV Delaware
Cruises 57-5, 58-3
Bluefin
Yellowfin
Bigeye
+ No Catch
Gulf Stream
Area
70°

Fig. 6 Distribution of dominant tuna species, summer season (July, Aug.), in the oceanic Northwest Atlantic

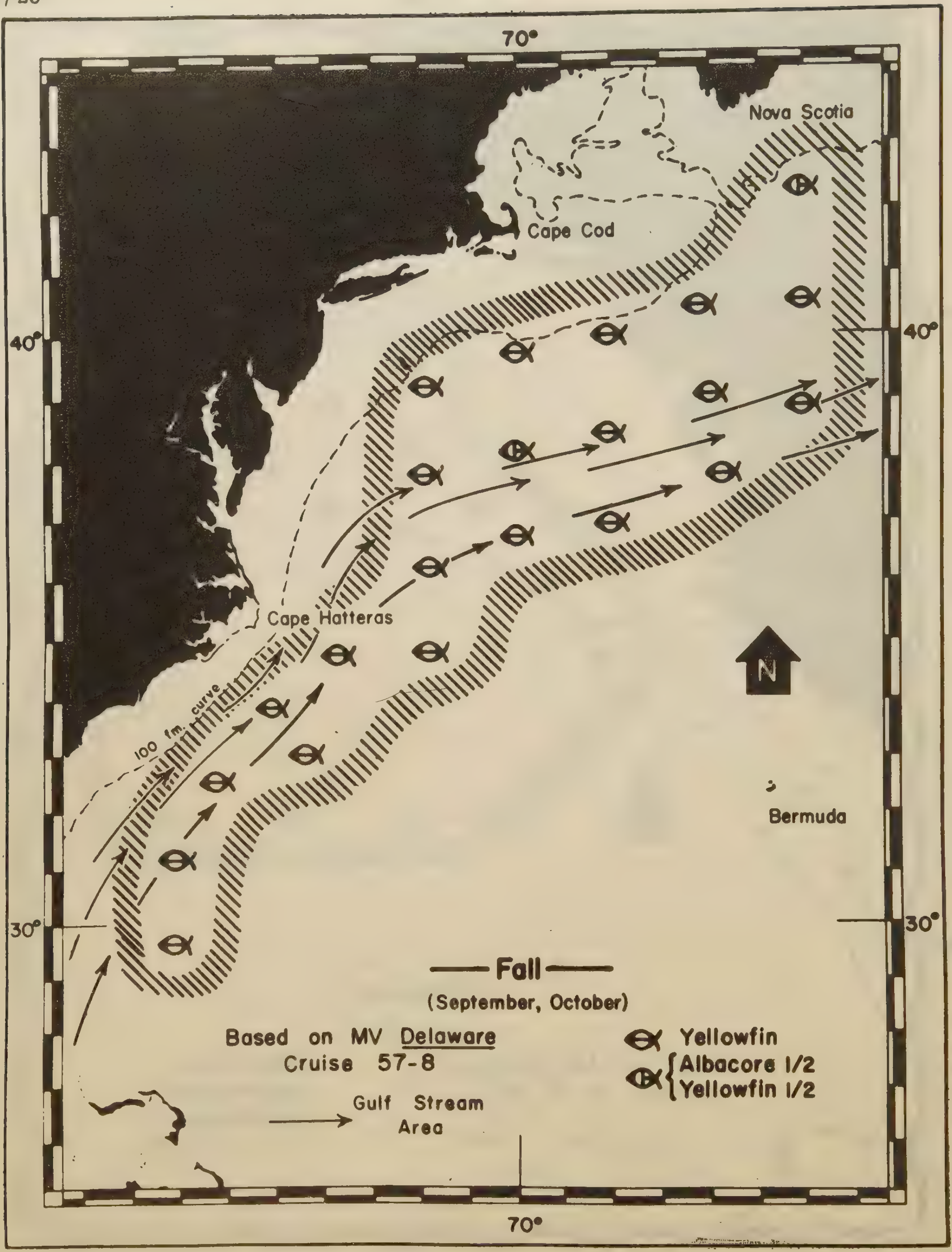

70°
Nova Scotia
Cape Cod
40°
Cape Hatteras
100 fm. curve
N
Bermuda
30°
Fall
(September, October)
Based on MV Delaware
Cruise 57-8
Yellowfin
Albacore 1/2
Yellowfin 1/2
Gulf Stream
Area
70°

Fig. 7 Distribution of dominant tuna species, fall season (Sept. Oct.) in the oceanic Northwest Atlantic

Appendix A: Fishing Log, MV *Delaware* explorations, 1957 to 1960

Cruise	Station	Date	Position or Station		Number of 10-hook Baskets	Species Number of Individuals	Tuna Catch Total (kg)	Catch per 100 Hooks Total	
			Lat.	Long.				Fish	kg
57-3	1	17-Mar.-57	39°48' N.	70°00' W.	24	BF 1	94.3	0.41	46.8
57-3	2	18-Mar.-57	36°32' N.	70°00' W.	40	-----	0.0	----	----
57-3	3	19-Mar.-57	36°40' N.	70°00' W.	1/ 29	2/BF 13 3/YF 5 4/A 2	1,505.9	6.89	519.2
57-3	4	22-Mar.-57	36°48' N.	74°00' W.	25	-----	0.0	----	0.0
57-3	5	26-Mar.-57	34°02' N.	73°18' W.	25	A 1	13.6	0.40	5.4
57-3	6	27-Mar.-57	32°05' N.	71°48' W.	30	A 3 BF 1	138.3	1.33	46.0
57-3	7	28-Mar.-57	29°45' N.	71°45' W.	35	A 3 YF 2	153.7	1.40	43.9
57-3	8	29-Mar.-57	29°45' N.	69°02' W.	40	A 3	61.2	0.75	15.2
57-3	9	30-Mar.-57	31°02' N.	66°45' W.	30	A 2 YF 1	111.1	1.00	37.0
57-3	10	31-Mar.-57	32°07' N.	64°48' W.	20	-----	0.0	----	----
57-3	11	4-Apri-57	31°09' N.	62°26' W.	35	-----	0.0	----	----
57-3	12	5-Apr.-57	31°12' N.	59°35' W.	45	A 4	58.9	0.88	13.0
57-3	13	6-Apr.-57	33°36' N.	59°36' W.	30	YF 3 A 1 BF 1	215.9	1.6	71.9
57-3	14	7-Apr.-57	33°36' N.	62°30' W.	30	A 1	20.4	0.33	6.8
57-3	15	8-Apr.-57	34°50' N.	65°00' W.	35	A 2 YF 1	36.7	0.85	10.4
57-5	16	8-June-57	40°26' N.	66°25' W.	25	BF 11 A 1	576.0	4.8	230.4
57-5	17	9-June-57	38°58' N.	66°26' W.	80	BF 35 YF 1 A 1	7,166.6	4.6	895.8
57-5	18	10-June-57	37°45' N.	66°32' W.	25	YF 4	94.8	1.60	37.9
57-5	19	11-June-57	37°30' N.	68°10' W.	40	BF 4	635.0	1.00	158.7
57-5	20	12-June-57	38°35' N.	68°12' W.	60	YF 23 BF 6	2,377.7	4.80	395.9

1/ 30 baskets set, 1 basket lost
2/ BF = Bluefin
3/ YF = Yellowfin
4/ A = Albacore

Appendix A: Fishing log, MV Delaware explorations, 1957 to 1960

Cruise	Station	Date	Position or Station		Number of 10-hook Baskets	Species Number of Individuals	Tuna Catch Total (kg)	Catch per 100 Hooks Total	
			Lat.	Long.				Fish	kg
57-5	21	13-June-57	40°04' N.	68°12' W.	38	BF 11 A 2	1,070.4	3.40	281.6
57-5	22	14-June-57	39°48' N.	70°00' W.	40	BF 6 A 1	271.2	1.75	67.8
57-5	23	25-June-57	38°17' N.	70°00' W.	50	YF 6 BF 3	952.5	1.80	190.5
57-5	24	27-June-57	37°02' N.	70°00' W.	60	YF 5 BF 2	771.1	1.16	128.5
57-5	25	28-June-57	36°46' N.	71°23' W.	62	YF 6 BF 2	737.1	1.29	118.8
57-5	26	26-June-57	37°48' N.	71°23' W.	60	A 2 YF 1	88.4	0.50	14.7
57-5	27	24-June-57	38°46' N.	71°23' W.	60	A 1	15.8	0.16	2.6
57-5	28	23-June-57	39°44' N.	71°23' W.	60	BF 3	419.5	0.33	69.8
57-5	29	3-July-57	37°59' N.	72°25' W.	60	------	0.0	----	----
57-5	30	30-July-57	35°53' N.	72°35' W.	50	YF 3	204.1	0.60	40.8
57-5	31	1-July-57	34°40' N.	73°41' W.	60	YF 18 BF 1	1,202.0	3.16	200.3
57-5	32	2-July-57	37°24' N.	73°40' W.	52	------	0.0	----	----
57-8	33	11-Sept.57	42°18' N.	64°02' W.	60	A 3 YF 3 5/ BI 1	204.1	1.16	34.0
57-8	34	12-Sept.-57	40° 34'N.	64°02' W.	60	YF 12 A 1	344.7	2.16	574.2
57-8	35	13-Sept.-57	38°49' N.	64°02' W.	60	YF 6 A 2 6/ SJ 1	185.9	1.50	30.9

5/ BI=Bigeye
6/ SJ=Skipjack

Appendix A: Fishing log, MV Delaware explorations, 1957 to 1960

Cruise	Station	Date	Position or Station		Number of 10-hook Baskets	Species	Number of Individuals	Tuna Catch Total (kg)	Catch per 100 Hooks Total	
			Lat.	Long.					Fish	kg
57-8	36	14-Sept.-57	37°44' N.	65°42' W.	60	YF SJ A	21 1 1	544.3	3.83	90.7
57-8	37	22-Sept.-57	39°07' N.	65°58' W.	60	YF A	37 8	995.6	7.50	165.9
57-8	38	21-Sept.-57	40°27' N.	66°15' W.	60	YF A	19 4	741.6	3.83	123.6
57-8	39	16-Sept.-57	40°00' N.	68°05' W.	60	YF	1	68.0	0.50	11.3
57-8	40	23-Sept.-57	38°28' N.	68°05' W.	40	YF A	10 4	521.6	3.50	130.1
57-8	41	25-Sept.-57	39°44' N.	70°00' W.	40	YF A	5 1	226.8	1.50	56.7
57-8	42	2-Oct.-57	36°57' N.	68°05' W.	60	YF A 7/BLF	27 1 1	640.4	4.80	106.7
57-8	43	3-Oct. -57	36°42' N.	70°00' W.	60	YF SJ	51 1	714.4	8.66	119.0
57-8	44	4-Oct.-57	38°12' N.	70°00' W.	60	A YF BI	12 12 1	816.4	4.00	136.0
57-8	45	7-Oct.-57	39°17' N.	71°49' W.	35	YF	4	172.3	1.14	49.2
57-8	46	8-Oct.-57	37°45' N.	71°49' W.	60	YF BI	34 1	725.7	5.83	120.6

7/ BLF = blackfin

Appendix A: Fishing log, MV Delaware explorations, 1957 to 1960

Cruise	Station	Date	Position or Station		Number of 10-hook Baskets	Species	Number of Individuals	Tuna Catch Total (kg)	Catch per 100 Hooks Total	
			Lat.	Long.					Fish	kg
57-8	47	9-Oct.-57	36°15' N.	71°49' W.	60	YF	24	451.3	4.33	75.2
						A	2			
57-8	48	10-Oct.-57	34°45' N.	71°49' W.	60	YF	12	278.9	2.00	46.4
57-8	49	11-Oct.-57	34°45' N.	73°41' W.	60	YF	10	90.7	1.83	15.1
						A	1			
57-8	50	16-Oct.-57	33°55' N.	75°13' W.	60	YF	13	526.6	2.66	87.7
						BI	1			
						BF	1			
						SJ	1			
57-8	51	17-Oct.-57	32°37' N.	76°20' W.	60	YF	9	555.6	1.66	92.5
						BF	1			
57-8	52	18-Oct.-57	31°16' N.	77°12' W.	60	YF	6	97.5	1.16	16.2
						BI	1			
57-8	53	19-Oct.-57	29°42' N.	77°12' W.	60	YF	9	258.0	1.83	43.0
						BI	1			
						SJ	1			
57-8	54	24-Oct.-57	33°02' N.	74°25' W.	60	YF	6	163.2	0.75	27.2
						A	2			
58-2	55	21-Apr.-58	41°09' N.	51°00' W.	60	BF	16	1,134.0	2.66	188.9
58-2	56	22-Apr.-58	39°36' N.	51°00' W.	60	BF	1	113.4	0.33	18.8
						A	1			
58-2	57	23-Apr.-58	39°20' N.	53°10 W.	60	------		0.0	----	----
58-2	58	24-Apr.-58	39°00' N.	55°20' W.	40	A	1	18.1	0.16	3.0
58-2	59	25-Apr.-58	40°32' N.	55°20' W/	60	BF	8	725.7	1.33	120.9
58-2	60	26-Apr.-58	42°02' N.	55°20' W.	40	BF	2	204.1	0.33	34.0
58-2	61	27-Apr.-58	41°46' N.	57°30' W.	42	A	1	15.8	0.23	3.7
58-2	62	10-May -58	39°14' N.	58°14' W.	60	BF	13	1,145.3	2.33	190.8
						A	1			

Appendix A: Fishing log, MV Delaware explorations, 1957 to 1960

Cruise	Station	Date	Position or Station		Number of 10-hook Baskets	Species		Tuna Catch Total (kg)	Catch per 100 Hooks Total	
			Lat.	Long.			Number of Individuals		Fish	kg
58-2	63	5-May-58	38°26' N.	59°40' W.	60	BF YF A	79 3 1	6,411.6	13.80	1,068.5
58-2	64	6-May-58	38°08' N.	61°50' W.	40	------		0.0	-----	----
58-2	65	7-May-58	39°40' N.	61°50' W.	60	BF A	3 2	334.7	0.83	55.7
58-2	66	11-May-58	41°10' N.	61°50' W.	60	BF	73	4,309.2	12.16	718.1
58-3	67	10-July-58	40°24' N.	66°42' W.	60	BI BF	7 4	739.3	1.83	123.1
58-3	68	11-July-58	38°57' N.	66°42' W.	60	YF A	13 1	907.2	2.33	151.1
58-3	69	12-July-58	37°42' N.	66°42' W.	60	YF SJ	11 1	555.6	2.00	85.0
58-3	70	13-July-58	37°03' N.	68°14' W.	40	YF	3	204.1	0.50	34.0
58-3	71	14-July-58	38°35' N.	68°14' W.	60	YF A	30 4	1,043.2	5.60	173.8
58-3	72	15-July-58	40°00' N.	68°14' W.	60	BI A BF	11 5 1	1,156.6	2.83	192.7
58-3	73	16-July-58	39°45' N.	70°00' W.	57	YF A BI	6 1 1	192.7	1.33	32.1
58-3	74	17-July-58	38°16' N.	70°00' W.	60	YF A	3 2	181.4	0.83	30.2
58-3	75	18-July-58	37°02' N.	71°20' W.	60	YF A	8 1	258.5	1.50	43.0
58-3	76	19-July-58	35°02' N.	72°35' W.	60	YF	1	45.3	0.16	7.5
58-3	77	24-July-58	34°44' N.	73°40' W.	60	BLF	1	6.3	0.16	1.0
58-3	78	25-July-58	33°06' N.	72°10' W.	60	------		0.0	----	----
58-3	79	26-July-58	32°06' N.	70°00' W.	60	YF	1	61.2	0.16	10.2

Appendix A: Fishing log, MV *Delaware* explorations, 1957 to 1960

Cruise	Station	Date	Position or Station		Number of 10-hook Baskets	Species	Number of Individuals	Tuna Catch Total (kg)	Catch per 100 Hooks Total	
			Lat.	Long.					Fish	kg
58-3	80	27-July-58	32°06' N.	67°32' W.	60	YF A	5 1	204.1	1.00	34.0
58-3	81	28-July-58	32°06' N.	65°05' W.	40	YF	2	113.4	0.50	28.3
58-3	82	31-July-58	34°00' N.	64°32' W.	60	-------		0.0	----	----
58-3	83	1-Aug.-58	36°05' N.	64°32' W.	60	YF	1	45.3	0.16	11.3
58-3	84	2-Aug.-58	39°21' N.	64°32' W.	60	YF BI	5 1	260.8	1.00	43.4
58-3	85	3-Aug.-58	41°19' N.	64°32' W.	60	YF	3	38.5	0.50	6.3
59-1	86	14-Jan.-59	40°24' N.	66°42' W.	30	-------		0.0	----	----
59-1	87	15-Jan.-59	38°57' N.	66°42' W.	45	BF A	15 5	1,031.9	4.40	229.2
59-1	88	18-Jan.-59	38°35' N.	68°14' W.	45	BF A BI	6 3 1	265.3	2.22	58.9
59-1	89	21-Jan.-59	38°16' N.	70°00' W.	45	BF A BI	25 1 1	1,623.8	6.00	360.8
59-1	90	23-Jan.-59	37°30' N.	71°33' W.	45	BF BI	2 1	161.0	0.66	35.7
59-1	91	24-Jan.-59	36°15' N.	72°28' W.	60	YF	7	104.3	1.55	23.1
59-1	92	29-Jan.-59	36°46' N.	70°00' W.	60	BF YF A	34 9 4	4,814.9	7.83	802.4
59-1	93	30-Jan.-59	37°03' N.	68°14' W.	48	BF YF	2 1	28.5	0.62	59.5
59-1	94	1-Feb.-59	37°24' N.	66°42' W.	45	BF A YF SJ	4 1 1 1	460.4	1.50	102.0
59-1	95	3-Feb.-59	35°39' N.	68°45' W.	50	A	1	13.6	0.20	2.7

Appendix A: Fishing Log, MV Delaware explorations, 1957 to 1960

Cruise	Station	Date	Position or Station		Number of 10-hook Baskets	Species	Number of Individuals	Tuna Catch Total (kg)	Catch per 100 Hooks Total	
			Lat.	Long.					Fish	kg
59-1	96	5-Feb.-59	39°45' N.	68°55' W.	41	A	2	27.2	0.40	6.6
59-6	97	20-May-59	38°48' N.	68°32' W.	60	BF	83	5,293.5	14.00	882.2
						BI	1			
59-6	98	21-May-59	38°49' N.	68°00' W.	60	BF	12	918.5	2.10	153.0
						A	11			
59-6	99	22-May-59	38°26' N.	68°15' W.	60	BF	53	3,955.3	8.80	659.2
59-6	100	23-May-59	38°06' N.	68°16' W.	40	YF	13	444.5	3.70	111.1
						BI	1			
						A	1			
59-6	101	24-May-59	38°37' N.	68°24' W.	60	BF	125	8,591.1	20.80	1,431.8
59-6	102	25-May-59	38°37' N.	68°24' W.	40	BF	54	3,769.4	13.50	942.3
59-6	103	26-May-59	38°38' N.	68°50' W.	60	BF	123	8,405.2	20.50	1,400.8
60-6	104	21-Aprl-60	35°00' N.	70°00' W.	60	YF	1	40.8	0.16	7.2
60-6	105	22-Apr.-60	35°33' N.	71°43' W.	60	A	1	18.1	0.16	2.9
60-6	106	23-Apr.-60	36°07' N.	73°25' W.	60	YF	85	3,524.0	14.10	587.3
60-6	107	24-Apr.-60	36°25' N.	74°21' W.	60	BF	3	163.2	0.50	27.2
60-6	108	1-May-60	37°58' N.	68°06' W.	40	YF	6	235.8	1.50	58.9
60-6	109	2-May-60	38°00' N.	65°25' W.	20	BF	1	233.6	2.50	116.8
						YF	4			
60-6	110	5-May-60	40°28' N.	62°29' W.	60	YF	4	369.2	1.10	61.5
						BF	3			
60-6	111	6-May-60	41°40' N.	64°01' W.	60	BF	21	1,714.6	3.50	285.7

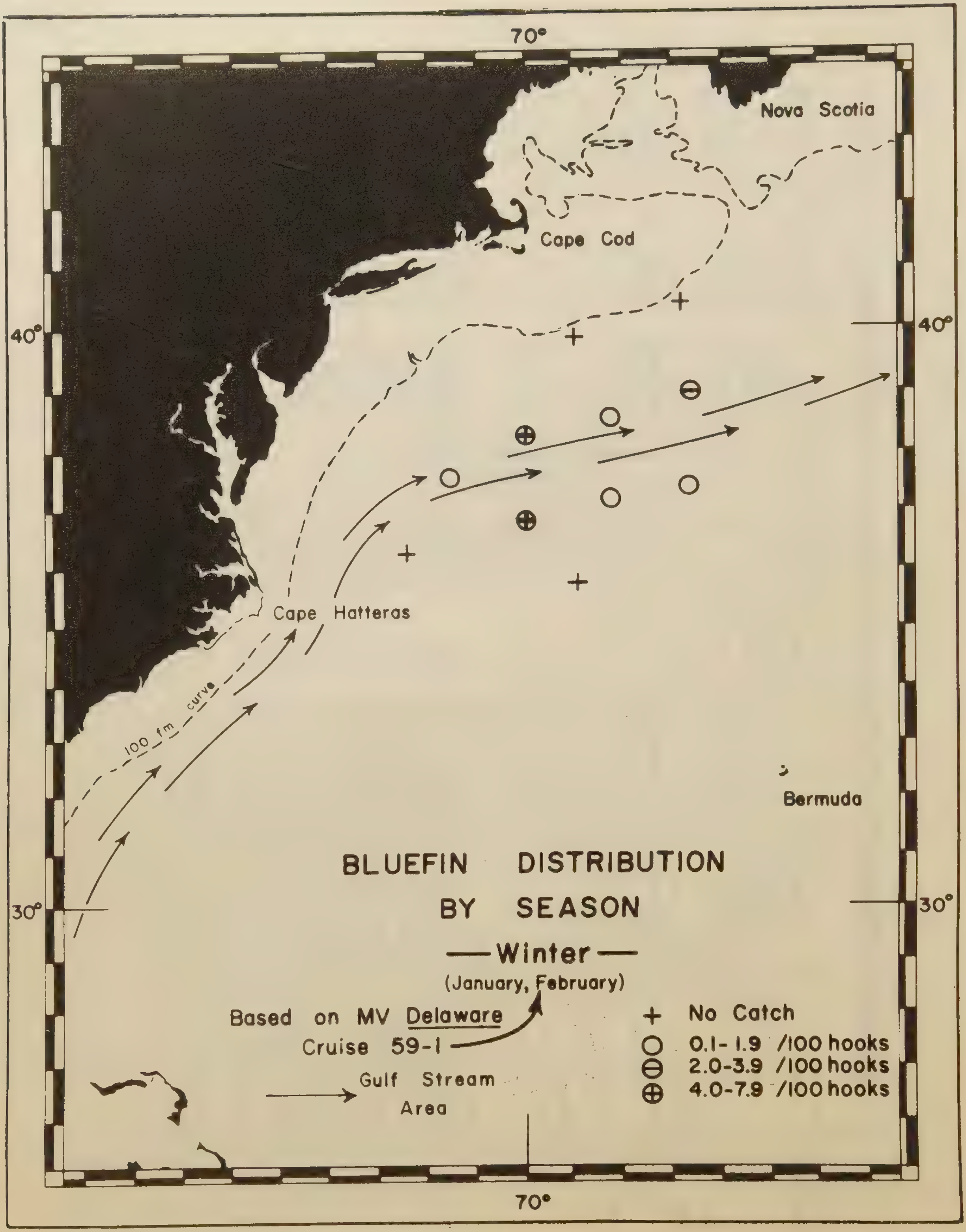
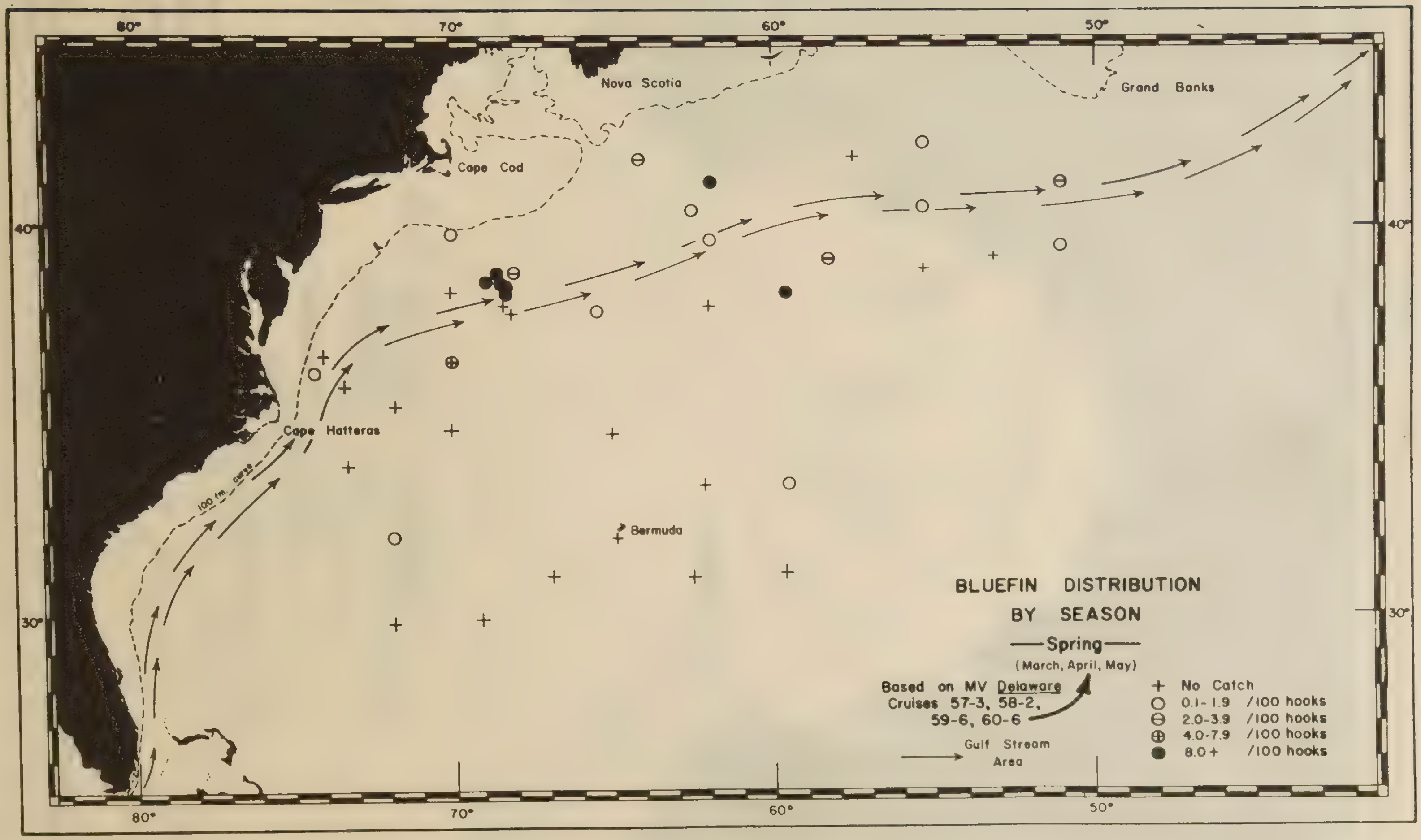
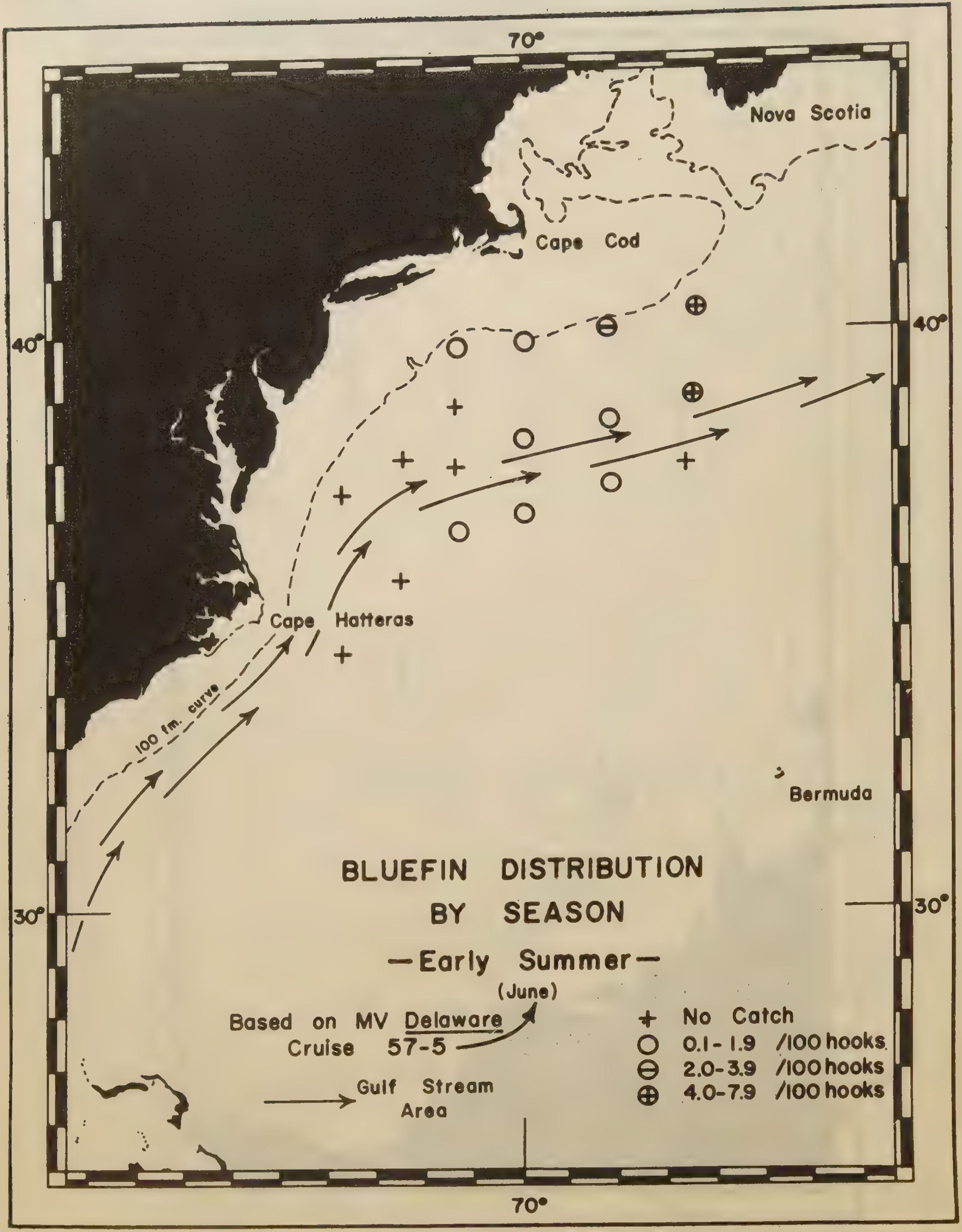

70°
Nova Scotia
Cape Cod
40°
Cape Hatteras
100 fm curve
Bermuda
30°
BLUEFIN DISTRIBUTION
BY SEASON
— Winter —
(January, February)
Based on MV Delaware
Cruise 59-1
Gulf Stream
Area
+ No Catch
○ 0.1-1.9 /100 hooks
⊖ 2.0-3.9 /100 hooks
⊕ 4.0-7.9 /100 hooks

Chart B_1 Observed distribution of bluefin in winter (January and February)


80°
70°
60°
50°
40°
30°
Nova Scotia
Grand Banks
Cape Cod
Cape Hatteras
100 fm curve
Bermuda
BLUEFIN DISTRIBUTION
BY SEASON
—Spring—
(March, April, May)
Based on MV Delaware
Cruises 57-3, 58-2,
59-6, 60-6
+ No Catch
○ 0.1-1.9 /100 hooks
⊖ 2.0-3.9 /100 hooks
⊕ 4.0-7.9 /100 hooks
● 8.0+ /100 hooks
Gulf Stream
Area

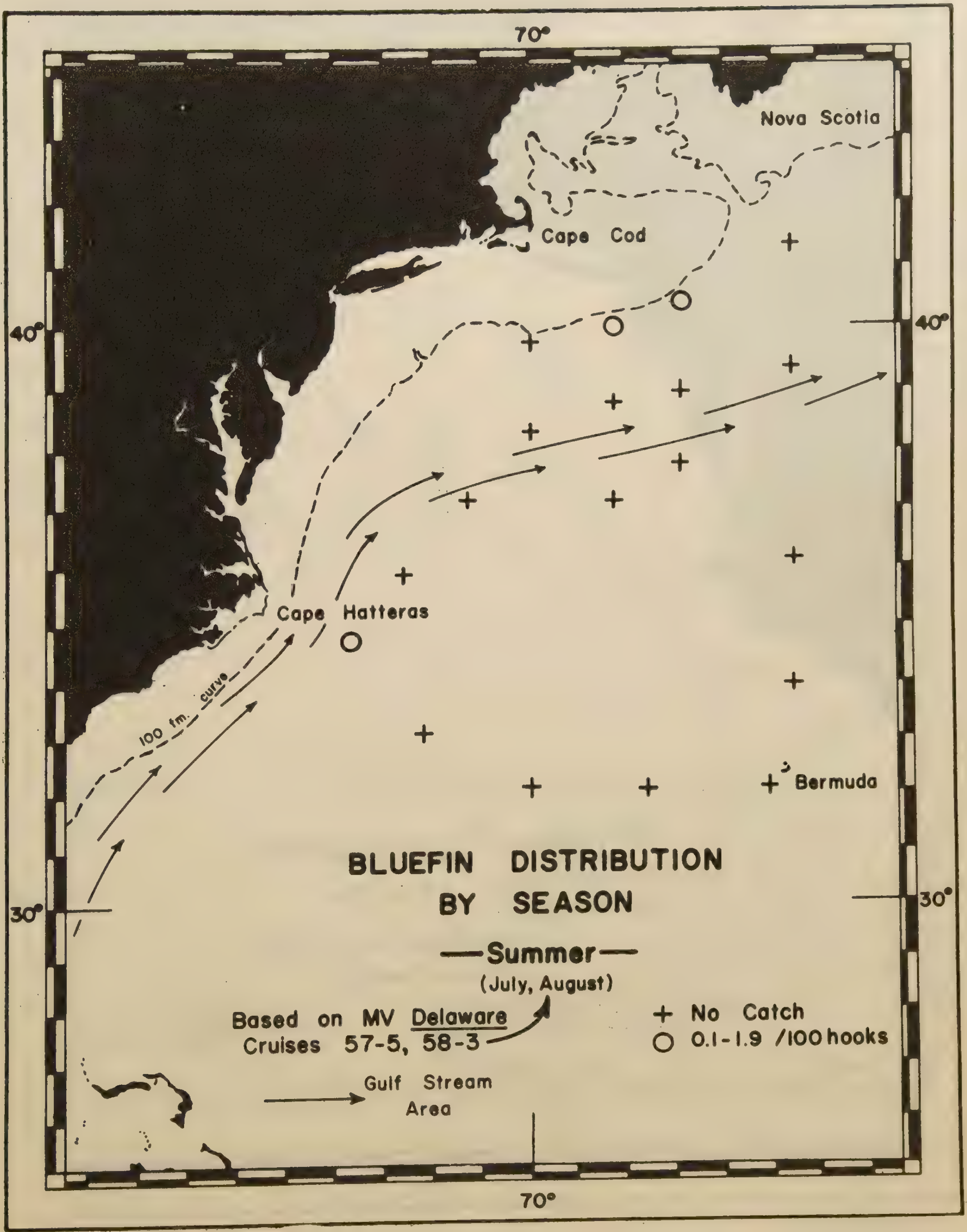
Appendix B

Chart B_2 Observed distribution of bluefin in spring (March, April and May)


70°
70°
40°
40°
30°
30°
Nova Scotia
Cape Cod
Cape Hatteras
100 fm. curve
Bermuda
BLUEFIN DISTRIBUTION
BY SEASON
—Early Summer—
(June)
Based on MV Delaware
Cruise 57-5
Gulf Stream
Area
+ No Catch
○ 0.1-1.9 /100 hooks
⊖ 2.0-3.9 /100 hooks
⊕ 4.0-7.9 /100 hooks

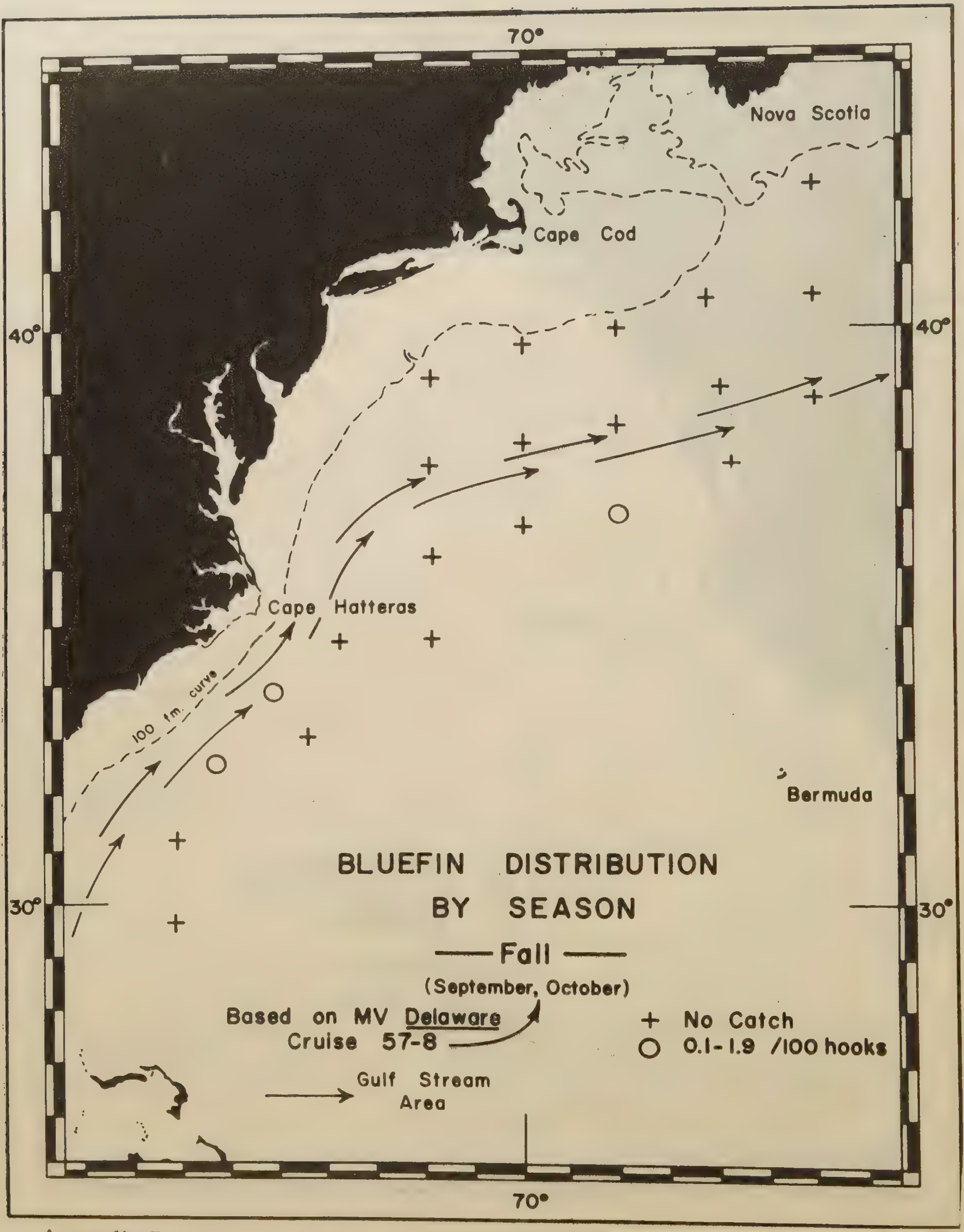
Appendix B

Chart B_3 Observed distribution of bluefin in early summer (June)


70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm. curve
Bermuda
BLUEFIN DISTRIBUTION
BY SEASON
—Summer—
(July, August)
Based on MV Delaware
Cruises 57-5, 58-3
+ No Catch
○ 0.1-1.9 /100 hooks
Gulf Stream
Area
30°
30°
70°

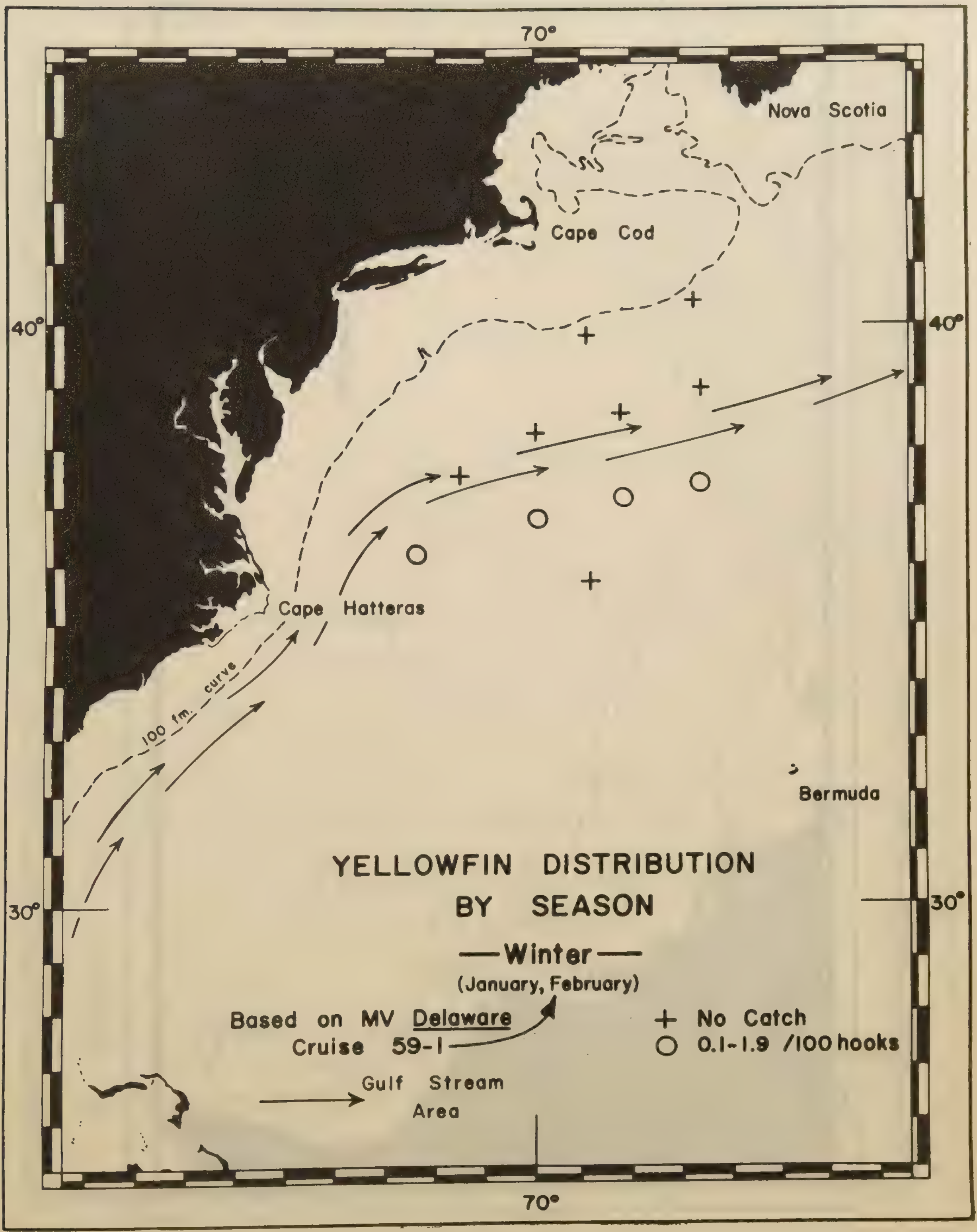
Appendix B

Chart B_4 Observed distribution of bluefin in middle and late summer (July and August)


70°
Nova Scotia
Cape Cod
40°
Cape Hatteras
100 fm. curve
Bermuda
30°
BLUEFIN DISTRIBUTION
BY SEASON
— Fall —
(September, October)
Based on MV Delaware
Cruise 57-8
+ No Catch
○ 0.1-1.9 /100 hooks
Gulf Stream
Area
70°

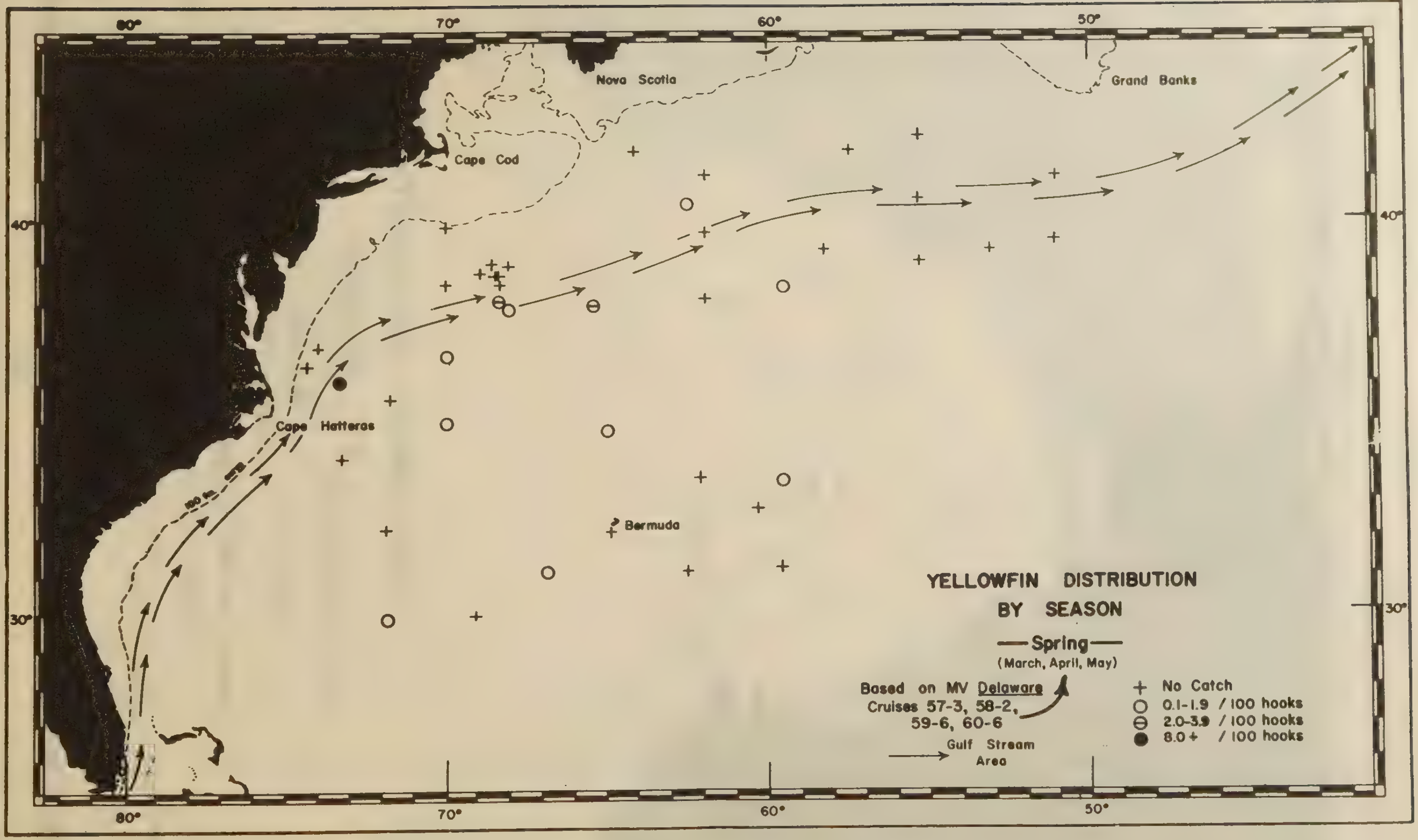
Appendix B

Chart B_5 Observed distribution of bluefin in fall (September and October)


70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm. curve
Bermuda
30°
30°
YELLOWFIN DISTRIBUTION BY SEASON
—Winter—
(January, February)
Based on MV Delaware Cruise 59-1
+ No Catch
○ 0.1-1.9 /100 hooks
Gulf Stream Area
70°

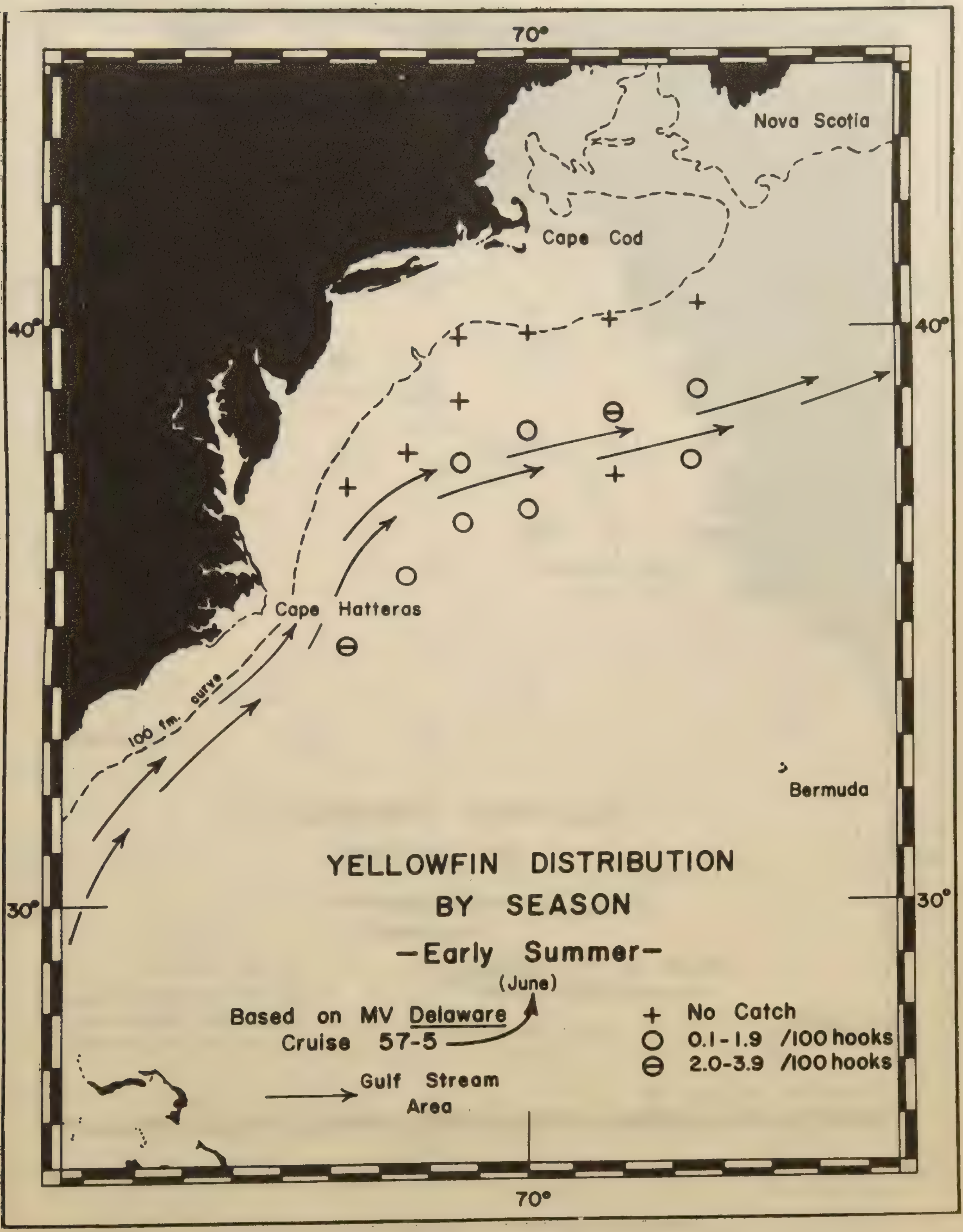
Appendix B

Chart B_6 Observed distribution of yellowfin in winter (January and February)


80°
70°
60°
50°
40°
30°
Nova Scotia
Grand Banks
Cape Cod
Cape Hatteras
100 fm.
Bermuda
YELLOWFIN DISTRIBUTION
BY SEASON
—Spring—
(March, April, May)
Based on MV Delaware
Cruises 57-3, 58-2,
59-6, 60-6
Gulf Stream
Area
+ No Catch
○ 0.1-1.9 / 100 hooks
⊖ 2.0-3.9 / 100 hooks
● 8.0+ / 100 hooks

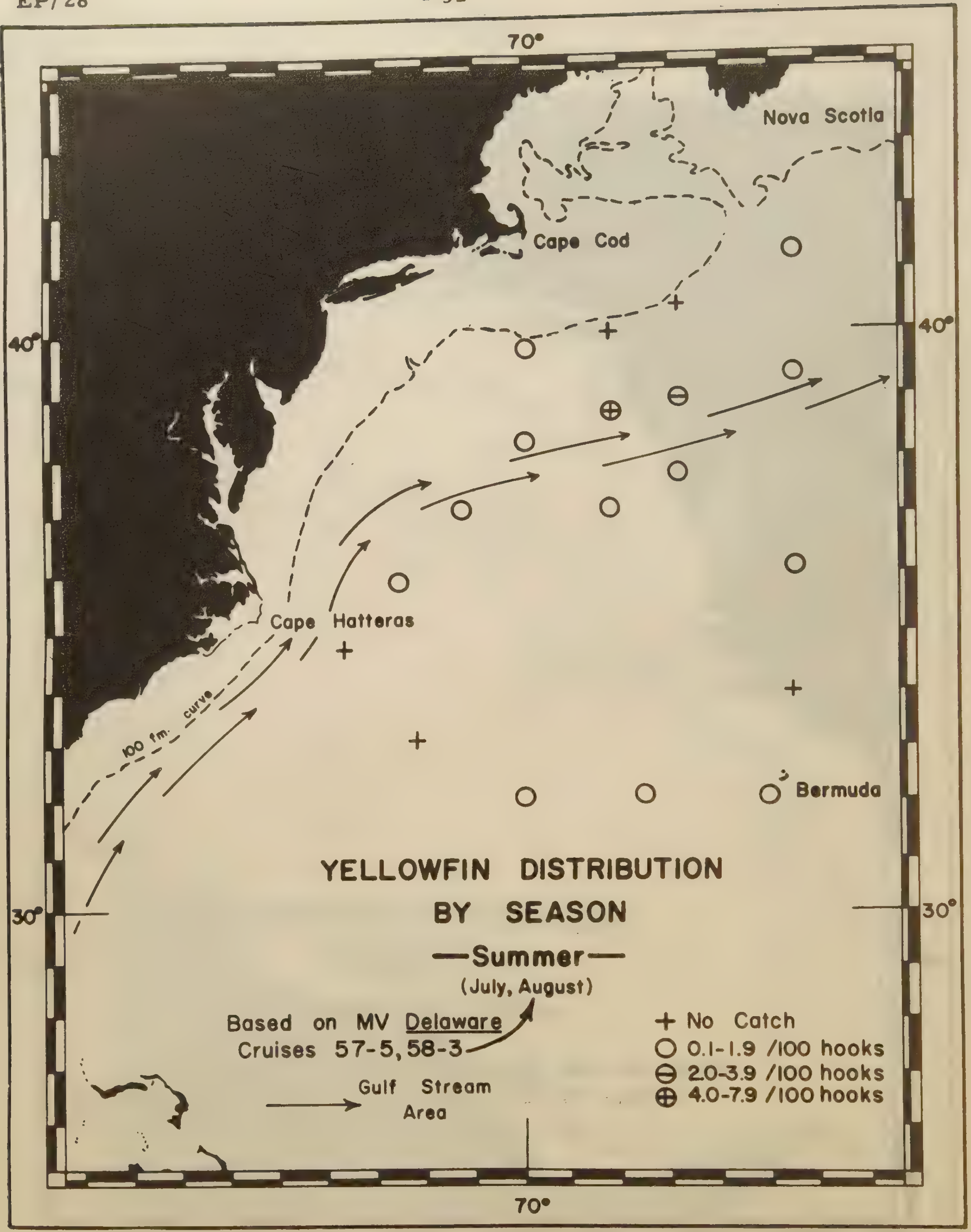
Appendix B

Chart B_7 Observed distribution of yellowfin in spring (March, April and May)


70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm. curve
Bermuda
30°
30°
YELLOWFIN DISTRIBUTION
BY SEASON
-Early Summer-
(June)
Based on MV Delaware
Cruise 57-5
+ No Catch
○ 0.1-1.9 /100 hooks
⊖ 2.0-3.9 /100 hooks
Gulf Stream
Area
70°

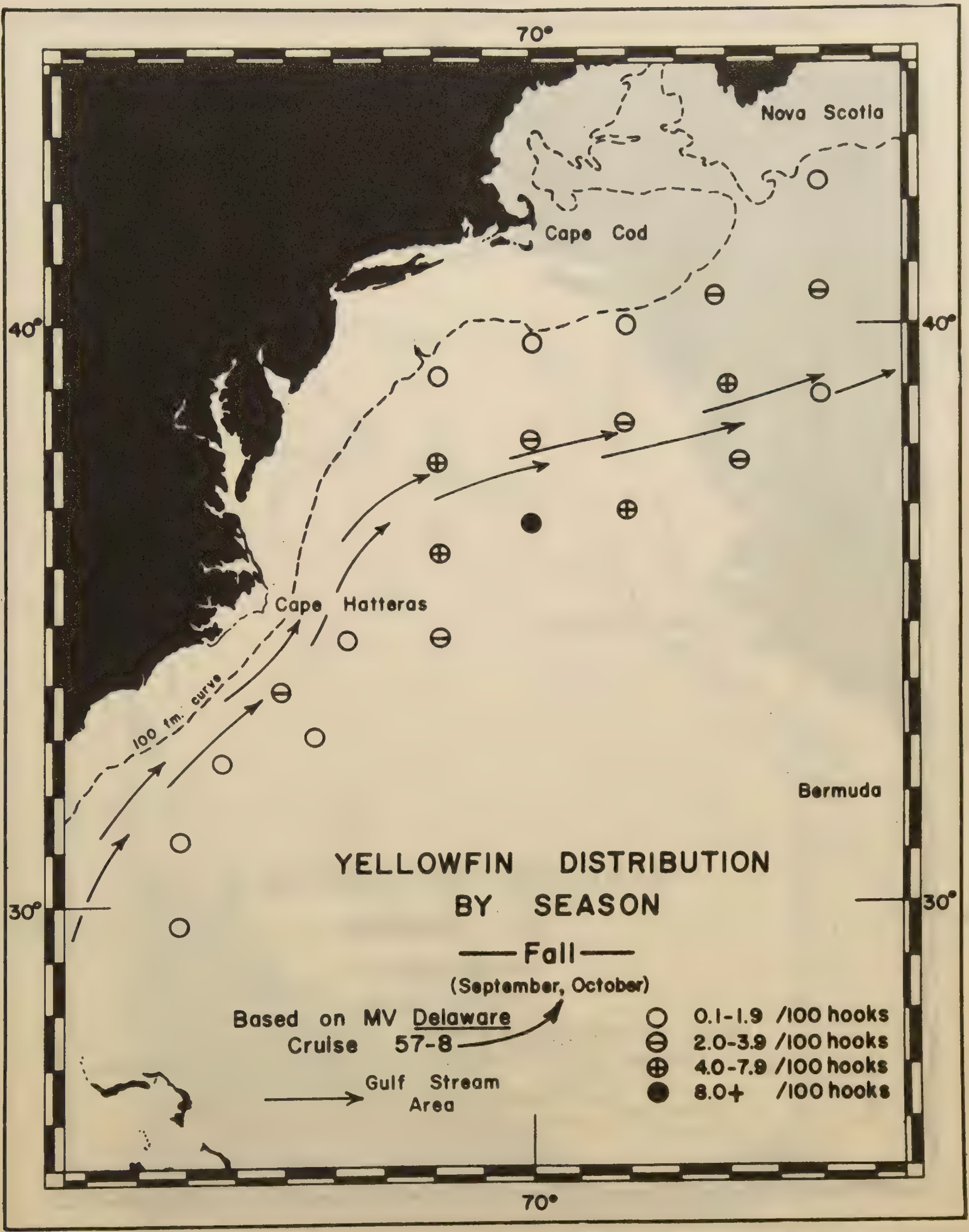
Appendix B

Chart B_8 Observed distribution of yellowfin in early summer (June)


70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm. curve
Bermuda
30°
30°
YELLOWFIN DISTRIBUTION
BY SEASON
—Summer—
(July, August)
Based on MV Delaware
Cruises 57-5, 58-3
Gulf Stream
Area
+ No Catch
○ 0.1-1.9 /100 hooks
⊖ 2.0-3.9 /100 hooks
⊕ 4.0-7.9 /100 hooks
70°

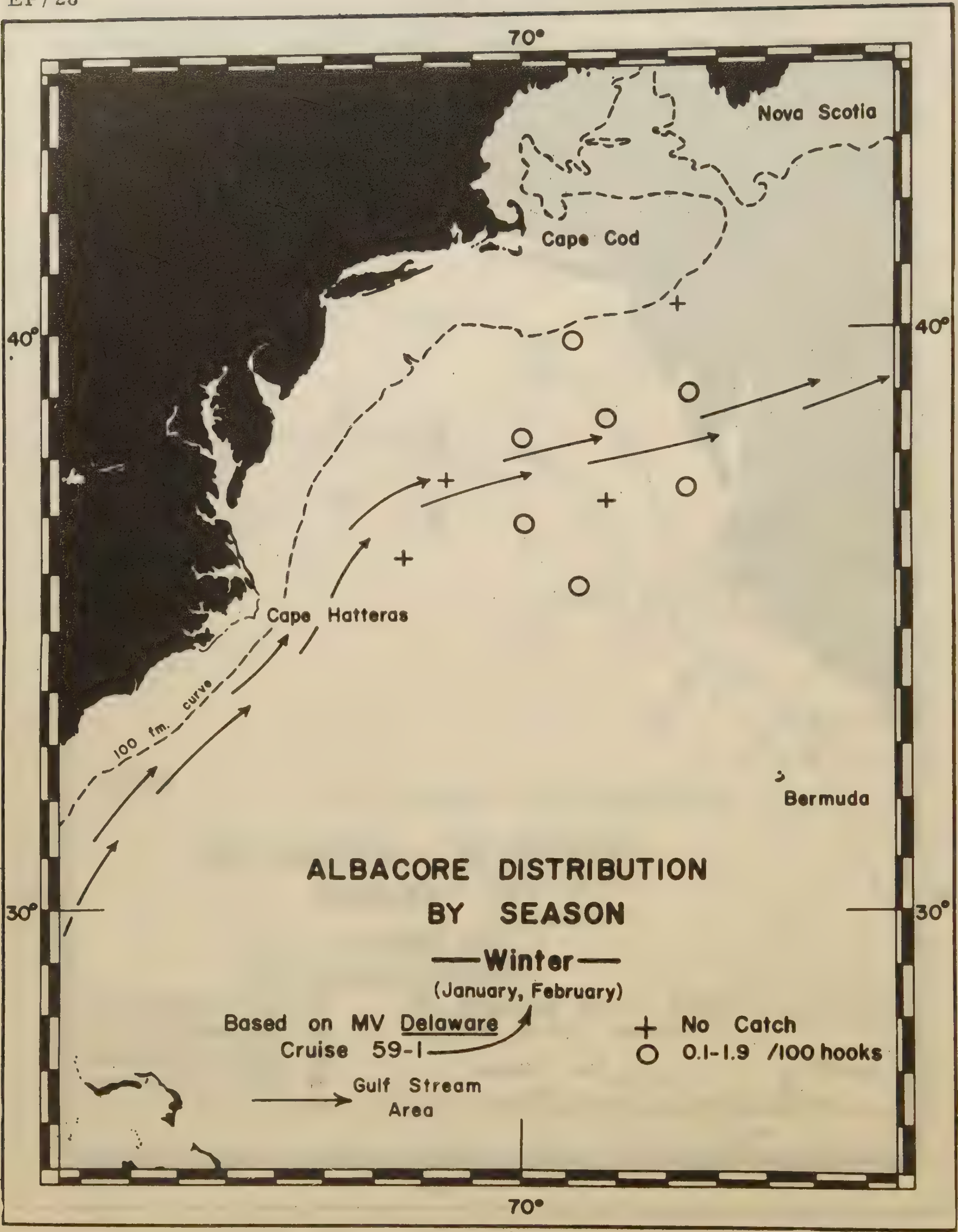
Appendix B

Chart B_9 Observed distribution of yellowfin in middle and late summer (July and August)


70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm. curve
Bermuda
30°
30°
YELLOWFIN DISTRIBUTION
BY SEASON
—— Fall ——
(September, October)
Based on MV Delaware
Cruise 57-8
Gulf Stream
Area
○ 0.1-1.9 /100 hooks
⊖ 2.0-3.9 /100 hooks
⊕ 4.0-7.9 /100 hooks
● 8.0+ /100 hooks
70°

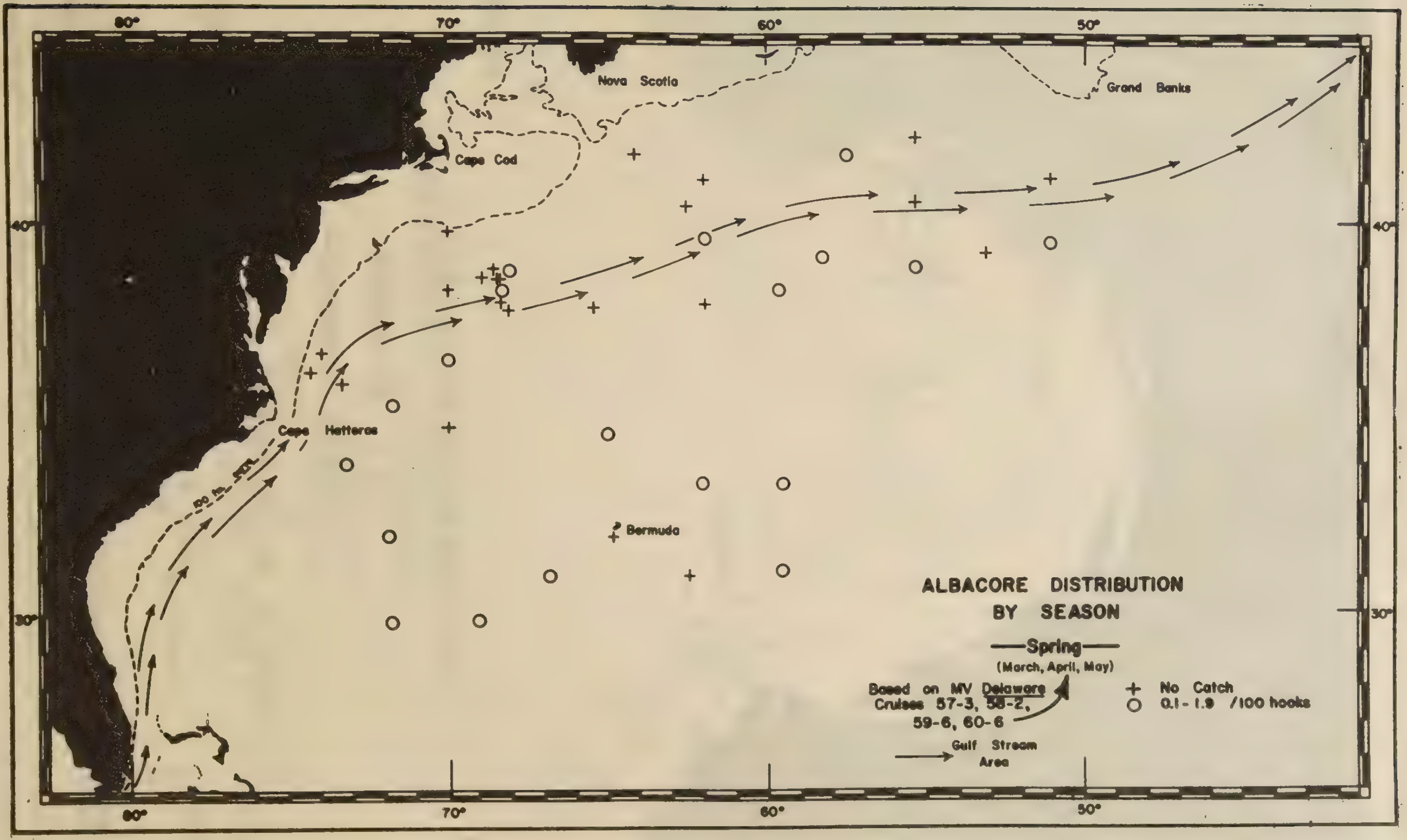
Appendix B

Chart B_{10} Observed distribution of yellowfin in fall (September and October)


70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm. curve
Bermuda
ALBACORE DISTRIBUTION BY SEASON
—Winter—
(January, February)
Based on MV Delaware Cruise 59-1
+ No Catch
○ 0.1-1.9 /100 hooks
Gulf Stream Area
30°
30°
70°

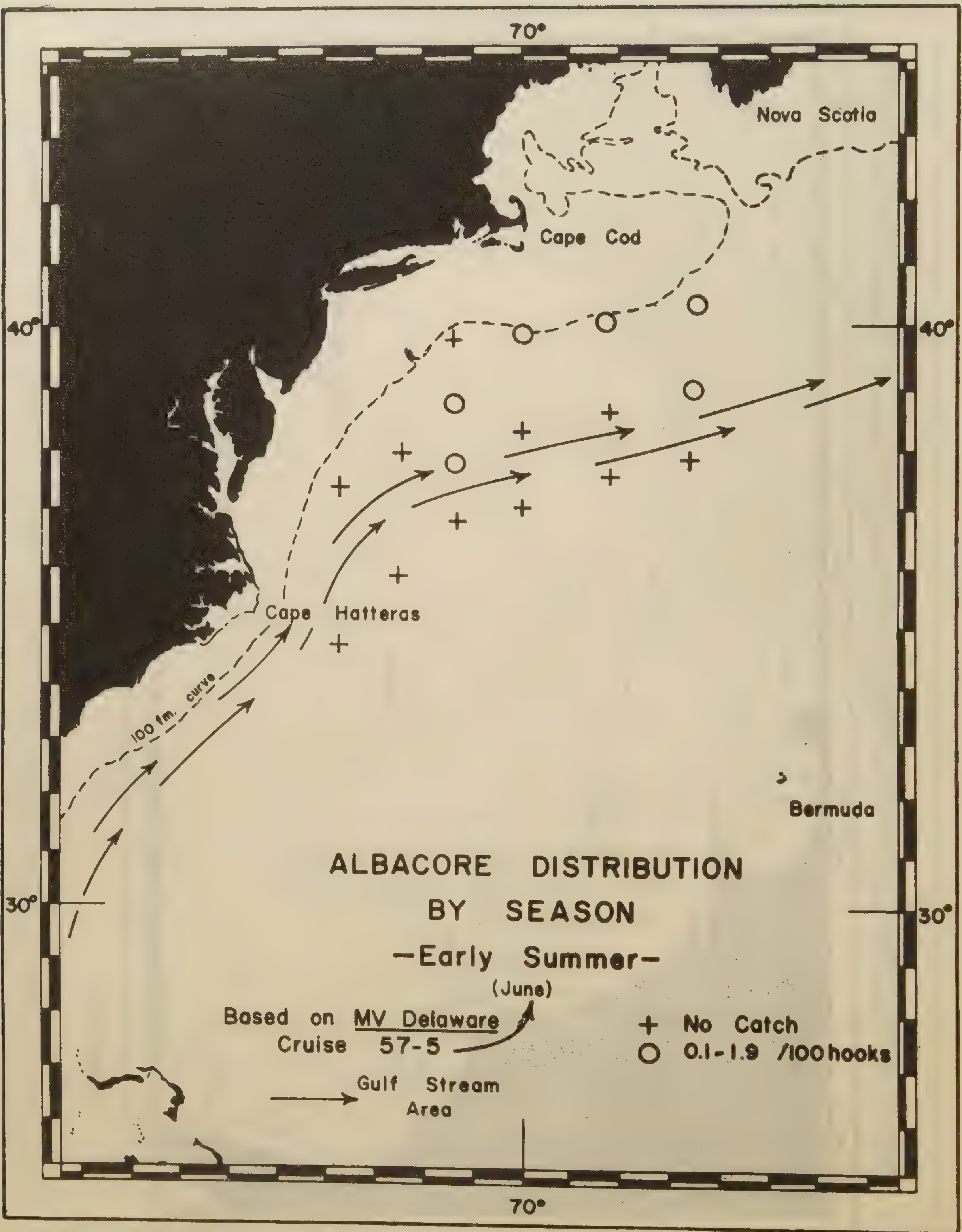
Appendix B

Chart B_{11} Observed distribution of albacore in winter (January and February)


ALBACORE DISTRIBUTION
BY SEASON
—Spring—
(March, April, May)
Based on MV Delaware
Cruises 57-3, 58-2,
59-6, 60-6
+ No Catch
○ 0.1 - 1.9 /100 hooks
Gulf Stream
Area
Nova Scotia
Grand Banks
Cape Cod
Cape Hatteras
100 fm.
Bermuda
80°
70°
60°
50°
40°
30°

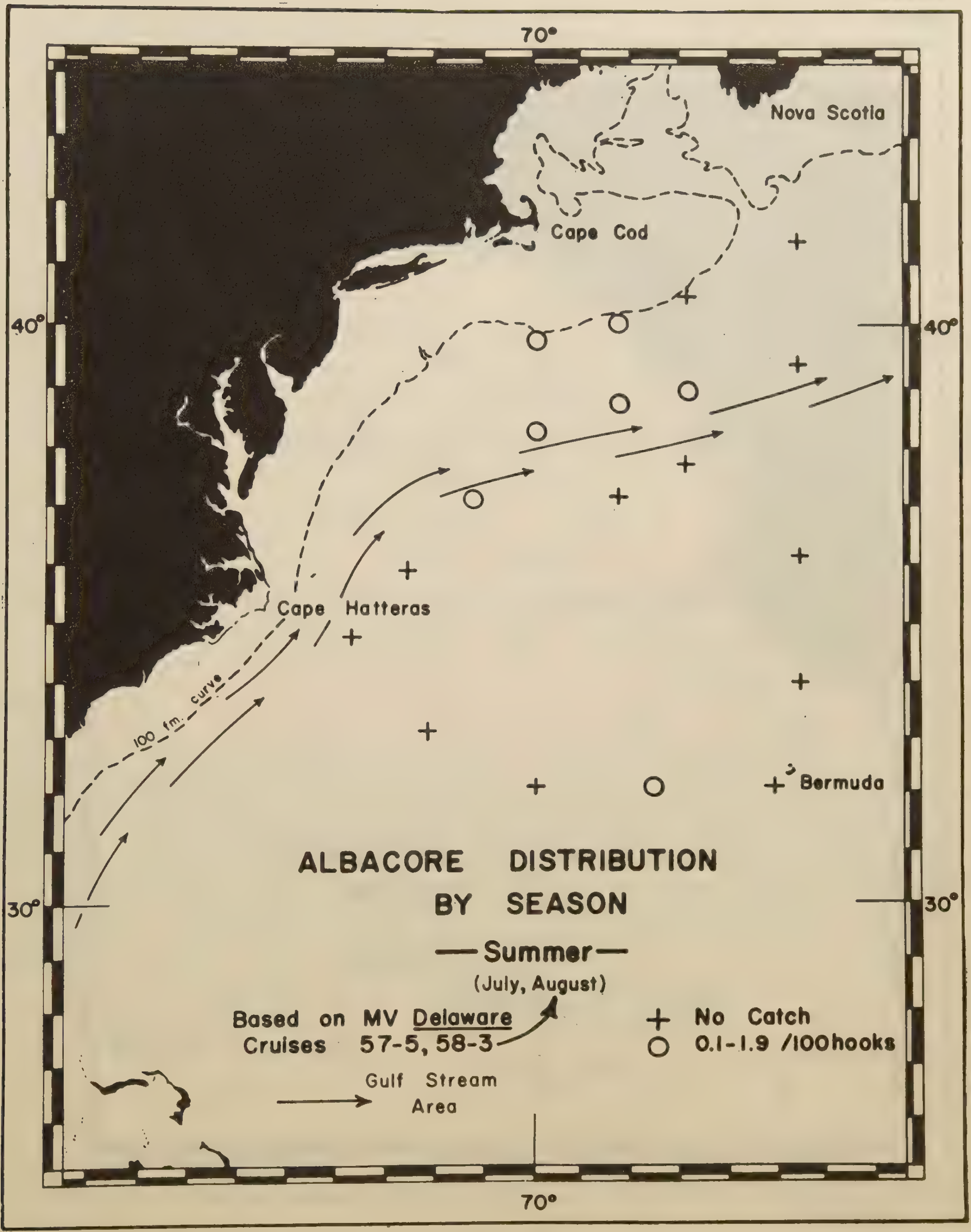
Appendix B

Chart B_{12} Observed distribution of albacore in spring (March, April and May)


70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm. curve
Bermuda
30°
30°
ALBACORE DISTRIBUTION
BY SEASON
-Early Summer-
(June)
Based on MV Delaware
Cruise 57-5
+ No Catch
○ 0.1-1.9 /100 hooks
Gulf Stream
Area
70°

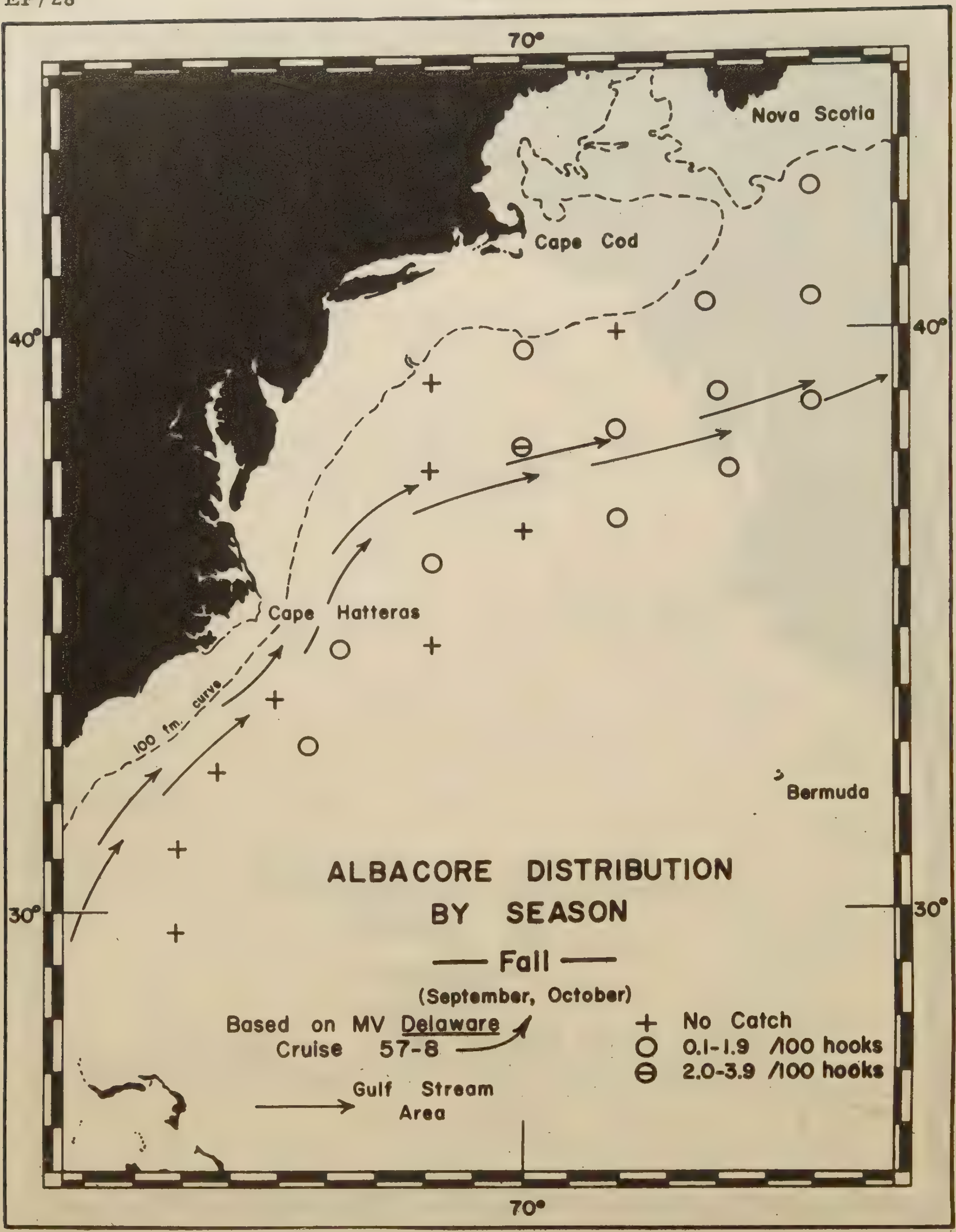
Appendix B

Chart B_{13} Observed distribution of albacore in early summer (June)


70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm. curve
Bermuda
30°
30°
ALBACORE DISTRIBUTION
BY SEASON
—Summer—
(July, August)
Based on MV Delaware
Cruises 57-5, 58-3
+ No Catch
○ 0.1-1.9 /100hooks
Gulf Stream
Area
70°

Appendix B

Chart B_{14} Observed distribution of albacore in middle and late summer (July and August)


70°
Nova Scotia
Cape Cod
40°
40°
Cape Hatteras
100 fm. curve
Bermuda
30°
30°
ALBACORE DISTRIBUTION
BY SEASON
— Fall —
(September, October)
Based on MV Delaware
Cruise 57-8
+ No Catch
○ 0.1-1.9 /100 hooks
⊖ 2.0-3.9 /100 hooks
Gulf Stream
Area
70°

Appendix B

Chart B_{15} Observed distribution of albacore in fall (September and October)

Experience Paper No. 29

A FIRST EXAMINATION OF THE ABUNDANCE AND DISTRIBUTION OF YELLOWFIN AND ALBACORE TUNA IN THE WESTERN TROPICAL ATLANTIC, 1957 to 1961 [1]

By

FLAVIO RODRIGUES LIMA

National Research Council of Brazil

and

JOHN P. WISE

Food and Agriculture Organization of the United Nations
Rome, Italy

Abstract

Although about 16 scombrids, istiophorids and miscellaneous species are regularly caught by Japanese longliners based in Brazil, yellowfin (Thunnus albacares) and albacore (Thunnus alalunga) make up some 75 percent of the catch by number. This paper is an analysis of catch-per-unit-effort for these species in the fishery in its first five years. The abundance of yellowfin is higher but more variable than that of albacore, and the former shows a clear seasonal distribution which albacore does not. The distributions with latitude of the two species are shown to be completely different, with yellowfin most abundant in the north and rarest in the south, while the albacore is most abundant in the central area of the fishery.

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[1] This paper has also been published in Portuguese as follows: Primeiro estado da abundancia e distribuição da albacora de laje e da albacora branca na região ocidental do oceano atlantico tropical (1957-1961) Bol. Estud. Pesca, Recife 2(10):12-7

EP/29

ETUDE PRELIMINAIRE DE L'ABONDANCE ET DE LA REPARTITION GEOGRAPHIQUE DU THON A NAGEOIRES JAUNES ET DU GERMON DANS L'ATLANTIQUE OUEST TROPICAL, 1957-1961

Résumé

Si les thoniers-palangriers japonais basés au Brésil capturent régulièrement quelque 16 espèces (scombridés, istiophoridés, etc.), 75 pour cent environ des prises, en nombre, sont constitués par des thons à nageoires jaunes (Thunnus albacares) et des germons (Thunnus alalunga). La communication étudie les captures par unité d'effort concernant ces deux espèces durant les cinq premières années de cette pêche. Par rapport à celle du germon, l'abondance du thon à nageoires jaunes est plus grande, mais plus variable, et ce poisson manifeste une nette distribution saisonnière, ce qui n'est pas le cas du germon. Le document indique une répartition géographique suivant la latitude totalement différente pour ces deux espèces, le thon à nageoires jaunes étant très abondant au nord et rare au sud, tandis que le germon se trouve surtout dans la partie centrale de la zone de pêche.

UN PRIMER EXAMEN DE LA ABUNDANCIA Y DISTRIBUCION DEL ATUN DE ALETA AMARILLA Y DE LA ALBACORA EN LA REGION TROPICAL OCCIDENTAL DEL ATLANTICO, 1957-1961

Extracto

Aunque los palangreros japoneses con base en el Brasil capturan regularmente alrededor de 16 escómbridos, istiofóridos y especies diversas, el 75 por ciento de las capturas, en cuanto a número, está constituido por atún de aleta amarilla (Thunnus albacares) y la albacora (Thunnus alalunga). Este trabajo constituye un análisis de las capturas por unidad de esfuerzo para tales especies en los primeros 5 años de la pesquería. La abundancia del atún de aleta amarilla es mayor, aunque más variable, que la de albacora, y la primera de dichas especies muestra una distribución estacional evidente, lo cual no ocurre con la albacora. Se observa que las distribuciones en latitud de estas dos especies son completamente diferentes, abundando más el atún de aleta amarilla en la parte norte y siendo más escaso en el sur, en tanto que la albacora alcanza su máxima abundancia en la zona central de la pesquería.

1 INTRODUCTION

de Moraes (in press) has studied the history of the development of the tuna fishery in the tropical Atlantic from Brazilian bases. He points out that previous to 1956, although tunas were known to be present and perhaps abundant off Brazil, there was only a small inshore fishery for about half of the year, during the southern spring and summer. In 1955 and 1956, at the invitation of the Brazilian Government, both the Food and Agriculture Organization (FAO) and the Japanese Government undertook investigations. These showed possibilities of fishery development on a truly commercial scale. Since 1957, Japanese longliners have been fishing from Recife, State of Pernambuco, and Santos, State of São Paulo, under special Presidential license. The landings have been considerable. Recently, however, there have been signs of a decrease in yield, which, along with labor problems and increased pressure to crew the vessels with Brazilian nationals, have doubtless contributed to the decrease in the number of units fishing from a peak of about 15 in 1958 to around half that number in mid-1962.

The data available show the fishery extending from almost 15°N (the level of the Windward Islands and Cape Verde) to about 35°S (Montevideo), and from 0°W (Accra) to nearly 55°W (French Guiana). However, within this area, the fishery has been prosecuted mostly between 10°N and 30°S, and west of 25°W, with a concentration inside a band of about 1200 nautical miles from the Brazilian coast.

In his analysis of the first three years' catch and effort data, de Moraes showed that although about 16 scombrids, istiophorids and miscellaneous species are regularly caught, two tunas, yellowfin (Thunnus albacares) and albacore (Thunnus alalunga), are by far the most common, making up some 75 percent of the catch by number. Yellowfin alone contributes more than half the total catch. (For scientific names with both English and Portuguese common names, see de Moraes, in press). With this in mind, we re-analyzed the first three years' data for the two most important species and added more recent material.

2 DATA, AND METHODS OF ANALYSIS

The original data are contained in logbooks kept by the captains during fishing operations. These logs record the catch by species and numbers for each set of the longline (which is almost invariably one day's work), the number of hooks used, a fishing position, meteorological and some hydrographic data. For the three years 1957 to 1959, the data are identical with de Moraes', from four vessels in 1957, eight in 1958, and eleven in 1959. We were able to obtain the records for only three boats for 1960 and 1961, but fortunately for our purposes, these three distributed their fishing rather widely over the area; we feel that the results with regard to abundance and distribution of the fish are representative of the fleet as a whole.

Monthly tabulations of the catch of yellowfin and albacore, together with the number of hooks used, were made for each year, by statistical rectangles of one degree of longitude by one degree of latitude. Each rectangle is numbered by the longitude on its eastern edge, by the latitude on its northern edge when it is south of the Equator, and on its southern edge when it is north of the Equator. At the Equator these rectangles are almost exactly 60 by 60 nautical miles, but at the southern limit, 35°S, they are 60 by approximately 50 miles due to the convergence of the meridians. This introduces no error unless the rectangles are considered as equal areas, and we have not done so. Error is introduced by the fact that the longline gear frequently, if not always, spans more than 60 miles, while the position given for the day is a point; the whole catch and effort are assigned to the rectangle within which that point lies. However, since the point is most likely the noon position of the fishing vessel, it is close to the center of the longline and, in any event, since the data are invariably grouped for analysis into areas larger than a single rectangle and since the area involved is so large, the error is minute.

From our data, the total catch in numbers of yellowfin and albacore, together with the total number of hooks (in reality hook-days), , and the overall abundance indices derived from them are shown in Table I. These may be converted on a very approximate basis to weights

Table I

Overall abundance indices of yellowfin and albacore

Year	Yellowfin	Albacore	No. of hooks	Catch/100 hooks (abundance)	
				Yellowfin	Albacore
1957	25,211	15,732	517,357	4.87	3.04
1958	26,145	14,265	467,647	5.59	3.05
1959	31,105	11,865	603,732	5.15	1.96
1960	13,200	12,437	555,025	2.37	2.24
1961	5,317	20,967	687,665	0.77	3.04
	100,978	75,266	2,831,426	3.56	2.66

of whole fish at 50 kg for yellowfin, 25 kg for albacore, and days fished at 1,750 hooks per day. Caution must be observed in any interpretation, for these are the raw data, not weighted in any way, from a varying percentage of the fleet in each year.

From our monthly tabulations we computed the quarterly and annual indices of abundance for each rectangle in which there was any fishing for each quarter, for each species, and constructed maps or charts, 48 in all, showing the abundance values in relation to geographic area.

3 ABUNDANCE

In his analysis, de Moraes (in press) grouped the data into three regions: North (of the Equator); Central (between the equator and 15°S); and South. However, in studying the monthly and quarterly charts for the five years but only for the two major species, we could not anticipate this division giving clearcut results - the only obvious break appeared around 15°S, where there had been no fishing in 3 or 4 degrees of latitude in any of the five years. Consequently, we divided the area only at the fifteenth parallel, combining de Moraes' North and Central areas into one, and calculated mean abundance indices by region and by quarter. Thus analysed, the yellowfin data gave understandable results, but the albacore did not, for reasons which became evident later and which will be shown below. Hence, we abandoned any attempt to divide the latter data on a geographical basis.

Fig. 1 shows the relative abundance of albacore and yellowfin by quarters for the five years of the study.

The yellowfin show a generally higher level of abundance than the albacore, with much greater absolute and relative oscillation, and a downward trend over the five years. The northern area shows a considerably higher level of abundance than the southern, with the low points in each year usually in the first and/or last quarter. The southern area data have almost exactly the opposite tendency, with the highest abundance levels occurring around the end of one year or the beginning of the next. This is suggestive of a migration from one area to the other, or perhaps merely an extension of the range farther south during the southern summer, with a withdrawal in the cooler months.

The overall picture for albacore is one of greater stability - after an abrupt fall from an almost suspiciously high initial level, there was a level of about four fish per hundred hooks for just over a year, then a drop to about half that for the last two years. There seems to be no obvious pattern with respect to seasons.

When the distributions in time of the abundance of the two species are examined together, there appears a tendency for one to be high when the other is low, illustrated most strikingly in mid-1959 when the albacore was at a five-year low and the yellowfin close to its five-year high. The reason for this is not clear, but it may perhaps be explained in one of two ways:

(a) there is some selectivity operating in the fishery which we do not as yet understand, or

(b) the fishing effort being common for both species, the fluctuations are due to some extraneous factor.

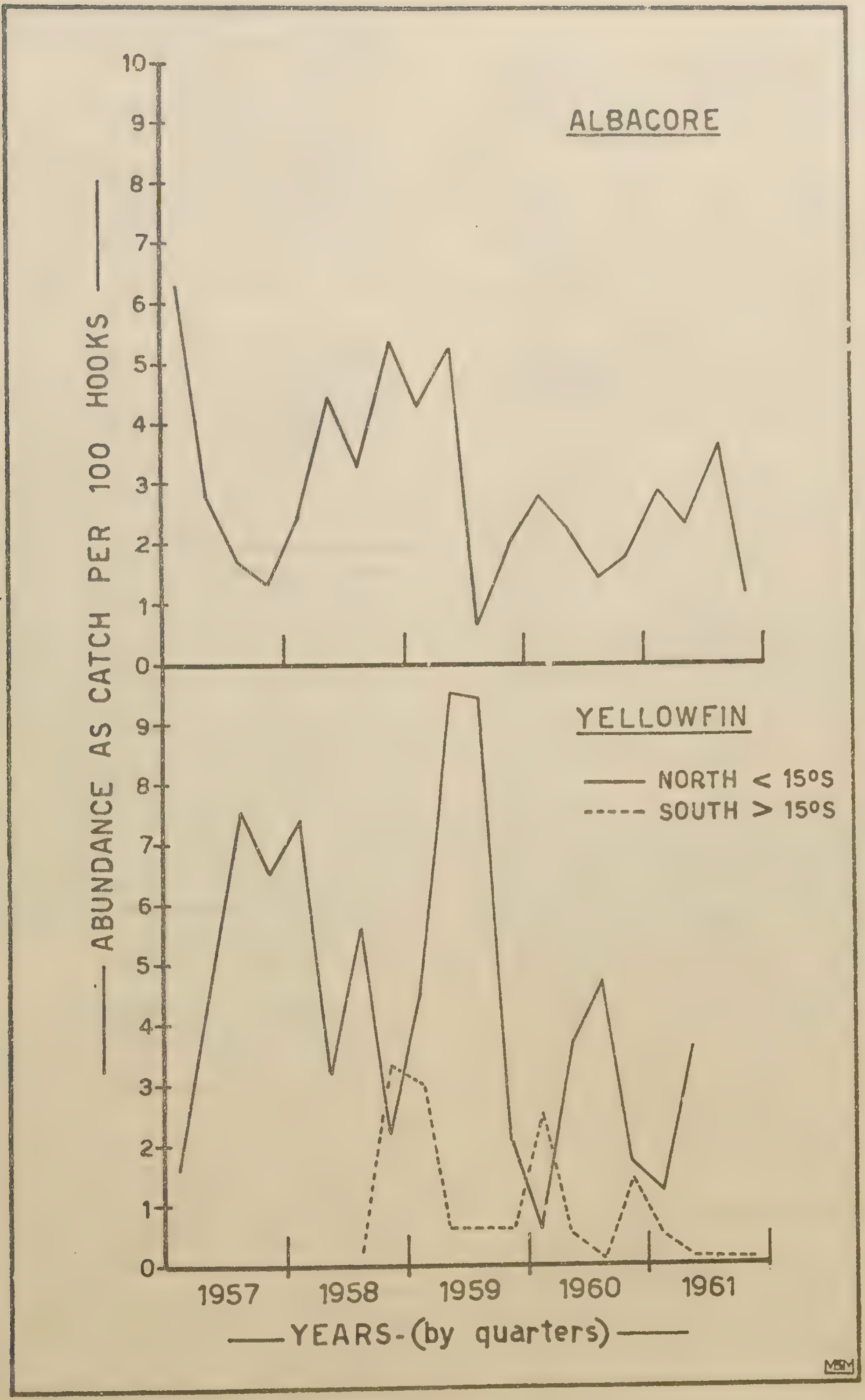

Fig. 1 Relative abundance of albacore and yellowfin tuna by quarters for 1957 to 1961

4 DISTRIBUTION

Fig. 2 shows the approximate mean abundance by degree of latitude for the two species, from pooled data for the five-year period. The curves are fitted by eye.

Abundance values shown are approximate because, as may be seen from Fig. 1, they include data from periods of high and low abundance, and we did not weight to assure their proportional representation at all latitudes (with one very minor exception, discussed below). Also the mean annual values were taken for each statistical rectangle in which any fishing occurred during the five years at each latitude, without regard to the amount of fishing in each.

Nonetheless, the differences between the distributions are striking. The yellowfin shows its highest abundance at the northern limit of the fishing area with a reasonably uniform but non-linear decrease to a very low level at the southern limit. The albacore, on the other hand, demonstrates a low abundance or near absence in the extreme north, a peak in the neighborhood of 15°S, and medium levels as far as the fishery is carried to the south, with an indication, by extrapolation, of continuing distribution even farther south.

(In the first analysis of the yellowfin curve we found the tendency for decreasing abundance with increasing latitude south of the Equator modified by an apparent increase south of 20°. However, when we re-examined the data, it was apparent that a few fishing trips were having an undue influence on the mean values for these latitudes. On further examination, it proved that the great majority of these "anomalous" trips had been made from November to February, the time of year in which the abundance in the southern region is unusually high, as shown in Fig. 1. Hence, we calculated median values, shown in Fig. 2 by the symbol "X", and used these in drawing the curve).

5 CONCLUSIONS AND DISCUSSION

When the relative abundance and distribution of yellowfin and albacore tuna are studied on the basis of catch and effort figures from the Brazil based longline fishery from 1957 to 1961, it is apparent that:

(a) the abundance of yellowfin is generally higher but considerably more variable than that of albacore.

(b) the abundance of yellowfin shows a definite seasonal distribution; the abundance of albacore does not.

(c) the distributions of the two species are completely different. The yellowfin is much more "tropical", with its center of distribution at least 25 degrees of latitude north of that for the albacore, while the range of the latter extends an as yet unknown (to us at least) but probably considerable distance to the south, outside of the tropics.

Some of the effects of these facts on the fishery are obvious, others are not. One very important consideration is that as yet the market to which the fishery is directed is not highly selective, nor is there any variation in price from one species to another, including the more than a dozen species caught along with the two most important. What is of prime consideration to the fisherman is the capture of the maximum number of tons of saleable product per voyage, but in this fishery under its present marketing arrangements, the major species of the catch are no more lucrative per unit of weight than the minor. Since about 25 percent of the catch is of miscellaneous species, if the net profit margin per voyage is less than 25 percent, as it probably is, financial success is dependent, at least part of the time, on the miscellaneous species. Thus, studies of the abundance and distribution of the major species, here the yellowfin and albacore, fall far short of an analysis of the fishery as a whole. However, it is not our purpose to enter in detail in economic considerations.

Obviously, the oceanographic régime of the region under study and its yearly variations are of importance in the variations observed. Emilsson (1959) has given the general picture, but the details and the secular pattern are as yet not well understood. As de Moraes (in press) pointed out, the distribution of the animals and the fishery are clearly related to the current pattern of the tropical Atlantic, but the exact relation is not understood, nor is the possible connection through this current system to the stocks of the African west coast. Further oceanographic studies directed at the current pattern and the pelagic fish populations, preferably with an augmented biological program including large-scale marking experiments on both sides of the tropical and sub-tropical Atlantic, would yield mutually complementary results.

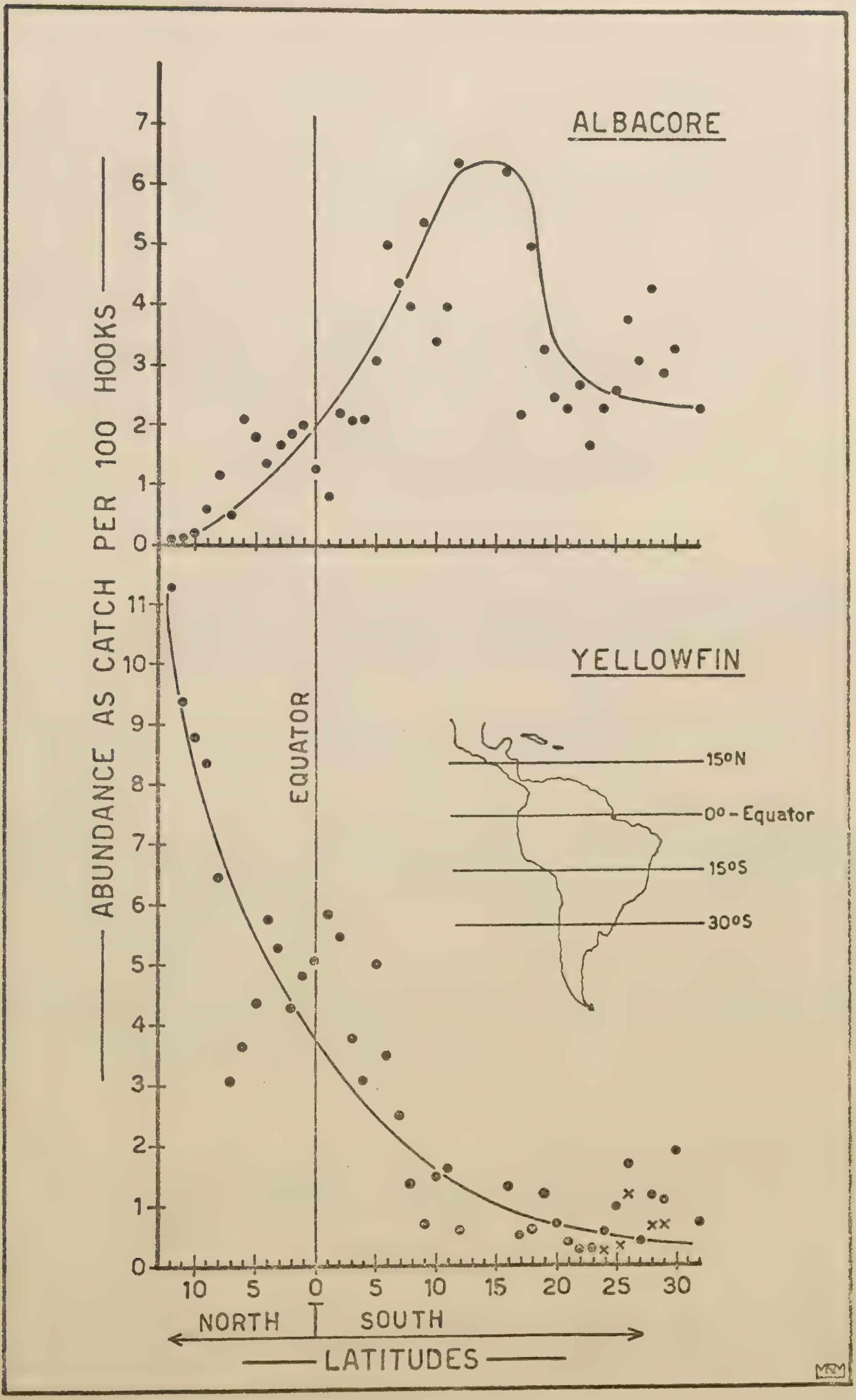

Fig. 2 Approximate mean abundance by degree of latitude for albacore and yellowfin tuna, from pooled data for 1957 to 1961

Experience Paper No. 30

FOOD OF PACIFIC ALBACORE IN THE CALIFORNIA FISHERY
(1955 - 1961)

By
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Abstract

Pacific albacore are not evenly distributed throughout their preferred sea-temperature range of 60° to 70° F (16° to 21° C); instead, they occur in concentrations that are constantly changing throughout the season.

Fluctuations in the location, abundance and availability of food organisms play important roles in regulating albacore movements and distribution.

Food items have been identified from albacore stomachs collected by fishermen and Department personnel from July 1955 to September 1961. These data indicate that albacore utilize the wide assortment of edible-sized marine organisms encountered during their travels. The most numerous items eaten were the ones thought to be most available.

Potential albacore feeding areas may be determinable by charting the offshore fishing grounds with respect to quantity of suitably-sized marine organisms irrespective of type.

ALIMENTATION DU GERMON DU PACIFICUE DES PECHERIES CALIFORNIENNES, 1955 - 1961

Résumé

Les germons du Pacifique (Thunnus germo) ne sont pas répartis de façon régulière dans leur domaine d'élection (température de l'eau située entre 16 et 21°C): ils forment des rassemblements qui se modifient constamment durant la saison.

Les variations dans l'emplacement, l'abondance et la disponibilité des organismes servant de nourriture jouent un rôle important dans la détermination des déplacements et de la distribution des germons.

D'après l'examen des contenus stomacaux rassemblés par les pêcheurs et par le personnel du Département de juillet 1955 à septembre 1961, le germon consomme toute une variété d'organismes marins de taille appropriée rencontrés durant ses déplacements. Il semble que ce soient les organismes les plus accessibles qui reviennent le plus souvent dans les contenus stomacaux.

Il serait peut-être possible de déterminer les zones d'alimentation éventuelles du germon en effectuant un relevé des lieux de pêche pélagiques du point de vue de la quantité d'organismes marins comestibles d'une taille appropriée, sans distinction d'espèces.

EL ALIMENTO DE LA ALBACORA DEL PACIFICO EN LA PESQUERIA CALIFORNIANA (1955 - 1961)

Extracto

La albacora del Pacífico no está distribuída uniformemente en toda la extensión de las aguas de 60 a 70°F (16 a 21°C), temperatura preferida por dicha especie; por el contrario, se presenta en concentraciones que están cambiando de lugar constantemente durante toda la temporada.

Las variaciones en cuanto a la situación, abundancia y disponibilidades de organismos alimenticios, desempeñan papeles importantes en cuanto a la regulación de los movimientos y distribución de la albacora.

En los contenidos estomacales de la albacora recogidos por los pescadores y por los funcionarios del Departamento desde julio de 1955 hasta septiembre de 1961, se han identificado los elementos constitutivos del alimento. De tales observaciones se deduce que la albacora utiliza la gran variedad de organismos marinos de tamaño comestible con que tropieza durante sus viajes. Los elementos más abundantes consumidos resultaron aquéllos que se supone más fácilmente disponibles.

Las zonas potenciales de alimentación de la albacora pueden ser delimitadas indicando en el mapa los lugares de pesca en función de los organismos marinos de tamaño apropiado, independientemene del tipo de ellos.

1 INTRODUCTION

Pacific albacore, *Thunnus germo*, are one of California's most valuable renewable resources. The catch fluctuates widely from year to year and fishermen experience seasons of success and failure; thus they are subject to an unstable feast-or-famine livelihood. Knowledge and understanding of albacore biology, life history, and ecology can, when applied, lend a degree of stability to the annual harvest.

Recent studies have shown that Pacific albacore prefer an environment delimited by sea temperatures between 60° and 70° F (16° and 21° C). However, they are not evenly distributed throughout these preferred temperatures but occur in seasonally-changing concentrations, and it is these concentrations that provide the most economical fishing (Clemens, 1961).

A number of factors might cause albacore to concentrate, during certain periods, in particular parts of their temperature regime. We believe, however, that fluctuations in the location, abundance and availability of desirable food organisms play an important concentrating role by regulating horizontal and vertical albacore movements and distribution.

With this in mind, we have, since 1955, taken advantage of every opportunity to study and identify items found in albacore stomachs from the American fishing grounds. Our main objectives were to identify the food organisms and eventually to locate areas of their abundance. By locating such food "reservoirs" immediately prior to the annual albacore migration, one may be able to anticipate, with some degree of confidence, areas within the albacore's preferred temperature range where they are likely to concentrate during the fishing season.

2 COLLECTING METHODS AND AREAS

Food items were collected in the eastern North Pacific by commercial albacore fishermen and by personnel aboard the Department's research vessels from July 1955 to September 1961. The material was not collected on a quantitative or qualitative basis; a few fishermen saved only items spit up in good condition, some brought in only the food items they considered to be "oddities", and others saved everything. All specimens came from the California and Baja California fishing grounds, mostly within 300 miles of shore.

We assigned the food organisms by origin of collection to four areas designated A, B, C and D. Area A extends from Cape Mendocino south to Point Arguello, California; area B is from Point Arguello to the Mexican border; area C extends south from the Mexican border to Point San Eugenio, Baja California; and area D lies south of Point Eugenio (Fig. 1). The albacore were caught near the surface on trolling or live-bait gear, with the exception of nine long-line-caught fish taken during August 1955 off northern Baja California (area C). Items from these stomachs were similar to those from surface-caught fish.

3 LIST OF FOOD SPECIES

The food items have been listed systematically (Tables I and II). The invertebrate arrangement is a modification of several classification systems, while the systematic arrangement of fish families follows the American Fisheries Society, 1960 and Roedel, 1962. Within families, we have listed all items alphabetically by genus and species. One or more letters and numbers follow each name. The letters represent capture areas, while each number is the quantity of food specimens. For example, A5 means that area A produced five specimens and ABCI means that one specimen was taken somewhere between Cape Mendocino and Point San Eugenio.

4 DISCUSSION

Albacore in the eastern North Pacific consume an assortment of food organisms; fishes lead in number and variety. Representatives of 30 fish families, including 35 species and 40 genera were identified. Our literature search revealed that 16 families, 23 genera, and 24 species of food items had not been reported previously in the eastern North Pacific from albacore stomachs. Northern anchovies (*Engraulis mordax*), rockfishes (*Sebastodes* sp.), jack mackerel (*Trachurus symmetricus*), Pacific sauries (*Cololabis saira*), and barracudinas (*Lestidium ringens* and *Magnisudis barysoma*) were the most numerous. Squids, euphausiids, pelagic amphipods and heteropods comprised most of the invertebrate diet.

Most of the stomachs used in this study were from albacore three years old and younger (weighing 20 pounds and less). These youngsters are usually well-scattered in the ocean's surface layers. The fishes upon which they fed were primarily post-larval or juvenile forms; these and the invertebrate foods also are rather widely scattered in the offshore surface layers.

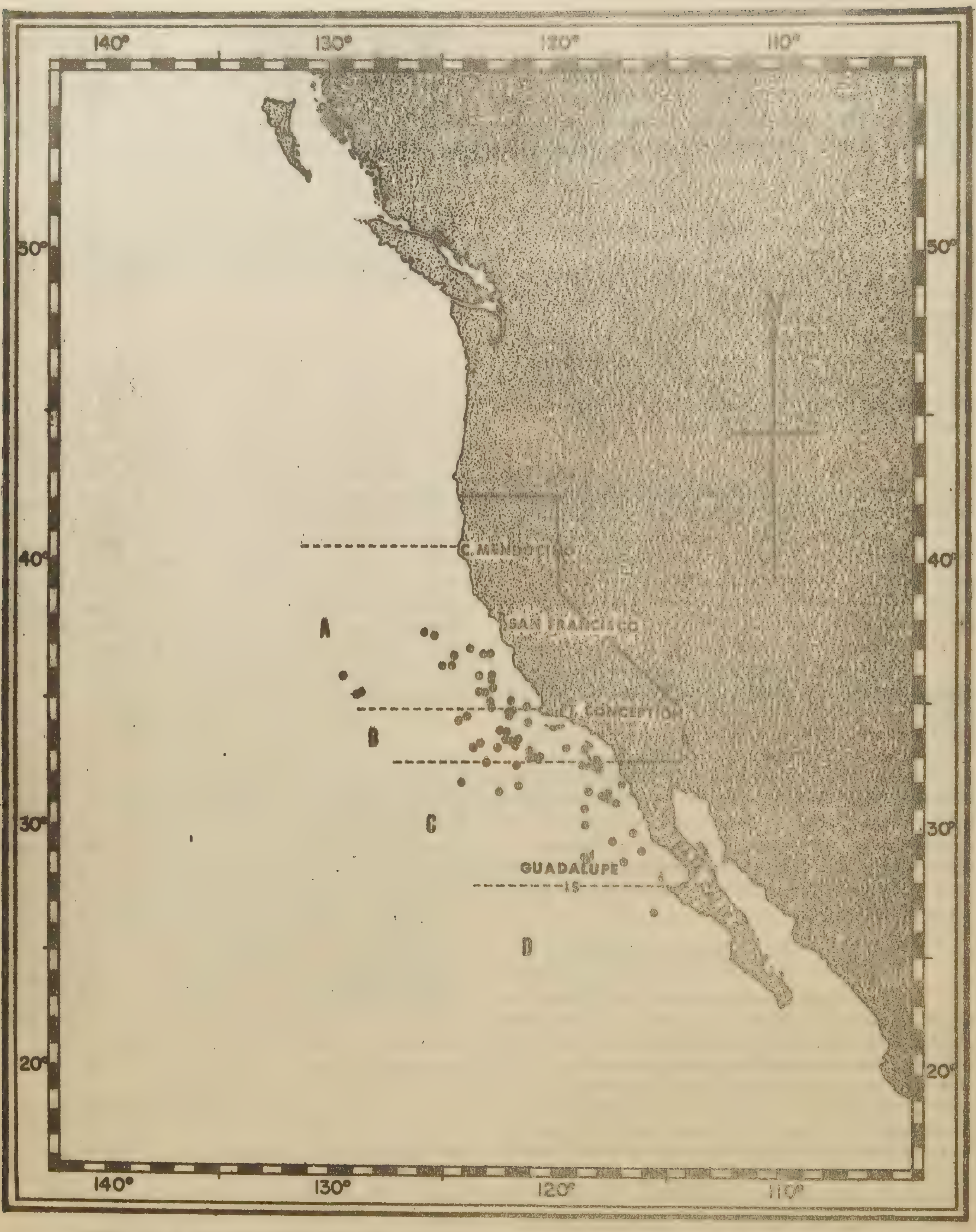
140°
130°
120°
110°
50°
40°
30°
20°
C. MENDOCINO
SAN FRANCISCO
PT. CONCEPTION
GUADALUPE IS
A
B
C
D

Fig. 1 Locations where albacore stomachs were collected from July 1955 to September 1961 are indicated by dots. In cases where specific data were not available, the food items were assigned to the broad areas (A, B, C and D)

TABLE I

A List of More Than 3, 309 Invertebrates Obtained From Albacore Stomachs (1955-1961)

Items	Area and Number
COELENTERATA	
Hydrozoa	
Siphonophora	
Velellidae	
Velella lata	A-B-C 1.
ARTHROPODA	
Crustacea	
Amphipoda	
Phronimidae	
Phronima sedentaria	A 14, B 25, C 5, A-B 2.
Phronima sp.	B 4.
Phrosinidae	
Phrosina semilunata	A 1, B 1, A-B 2.
Brachyscelidae	
Brachyscelus macrocephalus	A 1, B 1, A-B 1.
Platyscelidae	
Platyscelus armatus	A 1, B 1, C 1.
Unident. Amphipods	A 34, B 3, C 25, A-B-C 2.
Isopoda	
Unident. Isopods	C 2.
Euphausiacea	

TABLE I (con't)

Euphausiidae	
Euphausia sp.	A 256 +
Unident. Euphausiids	A 337 +, B 1,578 +, C 51, A-B 9, A-B-C 1.
Mysidacea	
Unident. Mysids	C 2, A-B-C 3.
Stomatopoda	
Squillidae	
Pseudosquilla sp.	B 1, C1.
Decapoda	
Galatheidae	
Pleuroncodes planipes	C 15.
Unident. Decapods	A 6, B 2, C 1, D 1.
Unident. Crustaceans	A 166, B 41, C 3, D 1.
MOLLUSCA	
Gastropoda	
Prosobranchiata	
Heteropoda (sub order)	
Carinariidae	
Carinaria lamarcki	A 49, B 31, C 2, A-B 4.
Unident. Gastropoda	A 5, B 3, C 4.
Cephalopoda	
Decapoda	
Cranchiidae	
Galiteuthis phyllura	B 1.

TABLE I (con't)

Unident. Decapods	A 172, B 58, C 42, A-B-C 31, B-C 1.
Octopoda	
Bolitaenidae	
Iapatella heathi	A 4.
Unident. Octopods	A 12, B 2, C 11, A-B-C 1, B-C 1.
Unident. Cephalopods	A 82, B 65, C 48, D 6, A-B 68.
CHORDATA	
Thaliacea	
Astigmatea	
Salpidae	
Salpa sp.	B 1, C 3.

TABLE II

A List of More Than 1,647 Fish Obtained From Albacore Stomachs (1955-1961)

Items	Area and Number
Clupeidae --- herrings	
Clupea pallasi	A 5.
Engraulidae --- anchovies	
Engraulis mordax	A 97 +, B 91, C 82, A-B 10, A-B-C 62, B-C 13.
Engraulids	A 33, B 63, C 52, A-B-C 2.
Argentinidae --- argentines	
Bathylagus wesethi	C 1.
Sternoptychidae --- lightfishes	
Sternoptyx diaphana	A 1, C 2.
Vinciguerria lucetia	B 5, C 31, A-B-C 1.
Melanostomiatidae --- scaleless dragonfishes	
Melanostomias valdiviae	B 1.
Photonectes margarita	A 1.
Paralepidae --- barracudinas	
Lestidium ringens	A 15, C 3.
Lestidium sp.	A 6, B 11, C 2, A-B 8, B-C 2.

TABLE II (con't)

Magnisudis barysoma	A 1, B 5, C 1.
Paralepids	A 10.
Anotopteridae --- daggertooths	
Anotopterus pharao	A 6, B 3, C 2.
Scopelarchidae --- pearleyes	
Scopelarchids	A-B-C 1.
Myctophidae --- lanternfishes	
Lampanyctus sp.	A 1.
Myctophum sp.	C 1.
Tarletonbeania crenularis	A 11, C 1, A-B 1.
Myctophids	A 2, B 8, C 3, A-B 2.
Scomberesocidae --- sauries	
Cololabis saira	A 7, B 9, C 37, A-B 2, A-B-C 14, B-C 2.
Exocoetidae --- flyingfishes	
Cypselurus sp.	C 1.
Gadidae --- codfishes and hakes	
Merluccius productus	C 7, B-C 4.
Centriscidae --- snipefishes	
Macrorhamphosus gracilis	C 4.
Syngnathidae --- pipefishes and seahorses	
Syngnathus californiensis	B-C 1.

TABLE II (con't)

Syngnathus sp.	B 4, C 1.
Syngnathids	B 3, C 2.
Trachipteridae --- ribbonfishes	
Desmodema polystictus	B 1.
Trachipterus trachypterus	A 3, B 3, C 2.
Carangidae --- jacks, scads, and pompanos	
Trachurus symmetricus	A 140, B 22, C 28, A-B 13, A-B-C 5.
Carangids	C 2.
Bramidae --- pomfrets	
Brama rayi	B 3, C 2.
Taractes asper	B 1.
Bramids	C 2.
Scorpidae --- halfmoons	
Medialuna californiensis	C 1.
Pomacentridae --- damselfishes	
Chromis punctipinnis	C 5.
Labridae --- wrasses	
Halichoeres nicholsi	C 1.
Scombridae --- mackerels and tunas	
Auxis sp.	C 1.
Pneumatophorus diego	D 1.

TABLE II (con't)

Gobiidae --- gobies	
Coryphopterus nicholsi	A 1.
Scorpaenidae --- rockfishes	
Sebastodes paucispinis	C 1.
Sebastodes sp.	A 138, B 37, C 49, D 3, A-B 4, A-B-C 11, B-C 3.
Sebastolobus sp.	B 3.
Scorpaenids	A 16, B 7, C 2.
Blenniidae --- combtooth blennies	
Blenniids	A 1.
Ophidiidae --- cusk-eels	
Ophidion novaculum	A 1, B 3, C 1.
Stromateidae --- butterfishes	
Cubiceps gracilis	C 2.
Icichthys lockingtoni	A 21, B 6, C 2, A-B 1.
Tetragonuridae --- squaretails	
Tetragonurus cuvieri	A 1, B 1, C 2, D 1, A-B-C 1, B-C 3.
Mugilidae --- mullets	
Mugil cephalus	C 1.
Bothidae --- lefteye flounders	
Citharichthys sordidus	A 1, B 2.
Citharichthys sp.	A 3, B 1.

TABLE II (con't)

Pleuronectidae --- righteye flounders	
Glyptocephalus zachirus	A 2.
Microstomus pacificus	A 1, B 1, C 1.
Pleuronichthys decurrens	A 2.
Pleuronichthys sp.	A 1.
Unident. Flatfish	A 2, C 1, D 2, A-B 4, B-C 1
Unident. Fish Remains	A 24, B 238, C 32, D 4, A-B 4, A-B-C 3, B-C 1.

Our data showed that albacore utilize the miscellany of edible-sized marine organisms encountered during their travels. Thus, the food items we have identified are not necessarily those preferred by albacore (assuming they have a preference), but simply those that were available.

Potential albacore feeding areas might be determined by searching the offshore fishing grounds for localities where there are quantities of suitably-sized organisms. This information could be obtained, on a quantitative basis, during preseason survey cruises by developing and utilizing specially-designed fishing or electronic gear in conjunction with standardized visual observations.

5 ACKNOWLEDGMENTS

We would like to extend our appreciation to the numerous fishermen who spent many extra hours at sea collecting food items. We especially thank R.G. Hamilton, Louis Zermatten, V.E. Kemp, Lon Ritchey, K.J. Ennis, R.F. Wadsworth and C.F. Wadsworth for unusually fine collections. In addition, John C. Nowell has contributed materially to this paper by identifying a number of the specimens, as has John E. Fitch.

Experience Paper No. 31

A MODEL OF ALBACORE MIGRATION IN THE NORTH PACIFIC OCEAN

By

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Abstract

Data concerning Pacific albacore, Thunnus germo, migration, age and growth rates together with detailed fishing, catch and oceanographic information have vastly increased our knowledge of albacore life history, biology and ecology. As a result, a working hypothesis or model of albacore migration in the north Pacific Ocean has been constructed and is presented as a convenient method of summarizing current information and thinking and as a basis from which to advance albacore researches.

Transpacific migrations of albacore between the western and eastern sectors of the ocean and various combinations of journeys within and between the current systems dominating each section are described. In addition, the extensive journeys of each age group, both near the surface and at depths, are set forth in some detail.

Finally, a few examples illustrate possible ways of using the model to guide research planning and to improve our understanding of albacore so they can be more fully and efficiently utilized. A major objective is to focus attention on areas where additional studies are needed.

This prototype migration model will be revised and improved at every opportunity and the increased knowledge will be made available to all who are interested.

SCHEMA TYPE DES MIGRATIONS DU GERMON DANS LE PACIFIQUE NORD

Résumé

Les connaissances actuelles sur le cycle vital, la biologie et l'écologie du germon du Pacifique (Thunnus germo) ont bénéficié dans une très grande mesure des données réunies sur les migrations, l'âge et le taux de croissance ainsi que des renseignements détaillés sur la pêche, les captures et l'océanographie. On a pu, sur ces bases, mettre au point une hypothèse de travail ou schéma type des migrations du germon dans le Pacifique Nord, qui permet de récapituler commodément les connaissances et les opinions du moment et fournit un point de départ à de nouvelles recherches sur cette espèce.

La communication décrit les migrations du germon entre les secteurs ouest et est du Pacifique, ainsi que diverses combinaisons de déplacements à l'intérieur des systèmes de courants prédominants dans chacun des secteurs et d'un système à l'autre. Elle fournit en outre des précisions sur les grands déplacements, tant près de la surface qu'en profondeur, de chacun des groupes d'âge.

Enfin, l'auteur illustre, à l'aide d'exemples, la manière dont le schéma type peut être employé pour organiser la recherche et améliorer les connaissances sur le germon en vue d'en tirer un meilleur parti. L'un des principaux objectifs est de mettre en évidence les domaines requérant un supplément d'étude.

Ce schéma type sera revu et perfectionné chaque fois que l'occasion se présentera, et les connaissances nouvelles mises à la disposition de tous les intéressés.

UN MODELO DE MIGRACION DE ALBACORA EN EL OCEANO PACIFICO SEPTENTRIONAL

Extracto

Los datos referentes migración, edad y ritmo de crecimiento de la albacora del Pacífico, Thunnus germo, junto con las noticias detalladas sobre su pesca, captura y oceanografía, han aumentado grandemente nuestros conocimientos del ciclo vital, biología y ecología de la albacora. Como consecuencia se ha construído y presentado una hipótesis válida o modelo de migración de albacora en el norte del Pacífico como método apropiado para agrupar los conocimientos e ideas actuales y como base para la continuación de los estudios sobre la albacora.

Se describen las migraciones transpacíficas de la albacora entre los sectores oriental y occidental del Océano, así como varias combinaciones de movimientos dentro de cada sistema de corrientes que dominan en cada una de las secciones, así como entre unos y otros sistemas. Además, se presentan con algún detalle los viajes de gran recorrido que hace cada grupo de edad, los mismo en la proximidad de la superficie que en profundidad. Finalmente, algunos ejemplos muestran las posibles formas de utilizar este modelo como guía para la planificación de las investigaciones y para mejorar nuestros conocimientos sobre la albacora, de forma que puedan ser utilizados más amplia y más eficazmente. Un objetivo principal es el de tratar de que se concentre la atención en las zonas en que se precisan nuevos estudios.

Este prototipo de modelo de migración será revisado y mejorado oportunamente, y los nuevos conocimientos se pondrán a disposición de los interesados en la materia.

1 INTRODUCTION

Pacific albacore, Thunnus germo, are fast-traveling migratory members of the tuna family, inhabiting the mixed layer of the temperate Pacific Ocean. In the eastern North Pacific, the most productive fishing grounds lie along the American coast between central Baja California and the Columbia River; they are within 400 miles of the mainland south of Point Conception, California, and within 300 miles of the coast north of there. During recent years, heaviest catches have been made south of Oregon. In the western North Pacific, best fishing is between the Sub-arctic water mass and the Subtropical Convergence area, within the latitudes of 25° to 40° N and from Japan to near the Hawaiian Islands (Fig. 1).

Albacore migration, age and growth studies revealed that the stocks in the principal North Pacific fishing grounds are closely related and fishermen apparently are harvesting a single population (Ganssle and Clemens, 1953; Blunt, 1954; Clemens, 1959, 1961a, 1961b; Otsu, 1960).

Studies also have shown that although the lengths overlap markedly among older albacore age groups, during certain seasons, many of the size or modal groups in the various Pacific fisheries are fairly distinct and may be analyzed as year-classes (Clemens, 1961b; Bell, 1962) that members of the smallest modal group (52 cm) are primarily one-year-old fish in their second year of life (Table I); and that over a period of years the North Pacific fishing fleets were successful in locating and following the fish schools, so that fleet movements usually reflected gross albacore migrations within the fisheries.

These data plus detailed fishing, catch and oceanographic information regularly obtained from cruises aboard both commercial and research vessels have greatly increased the knowledge and understanding of albacore life history, biology and ecology. As a result, a working hypothesis concerning albacore migrations in the North Pacific Ocean can now be constructed. This hypothesis or model, as presented, summarizes current information and thinking and forms a basis from which to advance albacore researches. The author has speculated freely in areas where there is little or no information and in many cases has deliberately gone into greater detail than the amount of reliable data warrants. A major objective is to focus attention on areas where additional studies are needed. The author plans to test, modify and improve this tentative model as investigations proceed and more information becomes available.

2 THE NORTH PACIFIC FISHERIES

2.1 The American fishery

The American fishery is seasonal; it peaks in August, and is most productive during the summer and autumn (June to November). During the past 15 years, most of the albacore in this fishery weighed 6 to 37 pounds (50 to 93 cm fork length), although a few in the 2-pound (37 cm) and 46-pound (100 cm) size groups have been recorded. Jig boats or trollers have accounted for the largest percentage of the catch, harvesting albacore weighing primarily 20 pounds (76 cm) and less. Live-bait boats, which land most of the remainder, catch fish that typically are 20-pounders and heavier (Clemens, 1961a). In recent years, purse-seiners using improved gear and techniques have made a significant contribution to the catch (Shaver, 1962). Seiners are most successful when large albacore ($\gg$ 20 pounds) are abundant.

2.2 The Japanese fisheries

The Japanese fisheries also are seasonal. Their longline fishery extends more than 3,000 miles offshore (Suda, 1956), peaks in January, and is most productive during the autumn and winter (October to March) when quantities of albacore weighing 6 to 79 pounds (50 to 129 cm) are caught -- most of the fish, however, weigh more than 16 pounds (70 cm). The Japanese "coastal" fishery extends some 1,000 miles offshore, peaks in June and is most fruitful during the spring and summer (May to July) when albacore primarily of 6 to 46 pounds (50 to 100 cm) are harvested by livebait methods. Most of the coastal fish weigh 16 to 33 pounds (70 to 90 cm). Commercially, the largest albacore are most abundant in the Japanese longline catches and the smallest in the American troll landings; medium-sized fish are the mainstay of both Japanese fisheries and usually make a major contribution to American live bait catches (Clemens, MS).

Table I

Calculated average lengths and weights for albacore age groups

Age	Fork Length (cm)	Increment (cm)	Weight (lbs)	Increment (lbs)
I	52	13	6.4	6.2
II	65	11	12.6	7.4
III	76	9	20.0	8.0
IV	85	8	28.0	8.6
V	93	7	36.6	8.9
VI	100	5	45.5	7.2
VII	105		52.7	

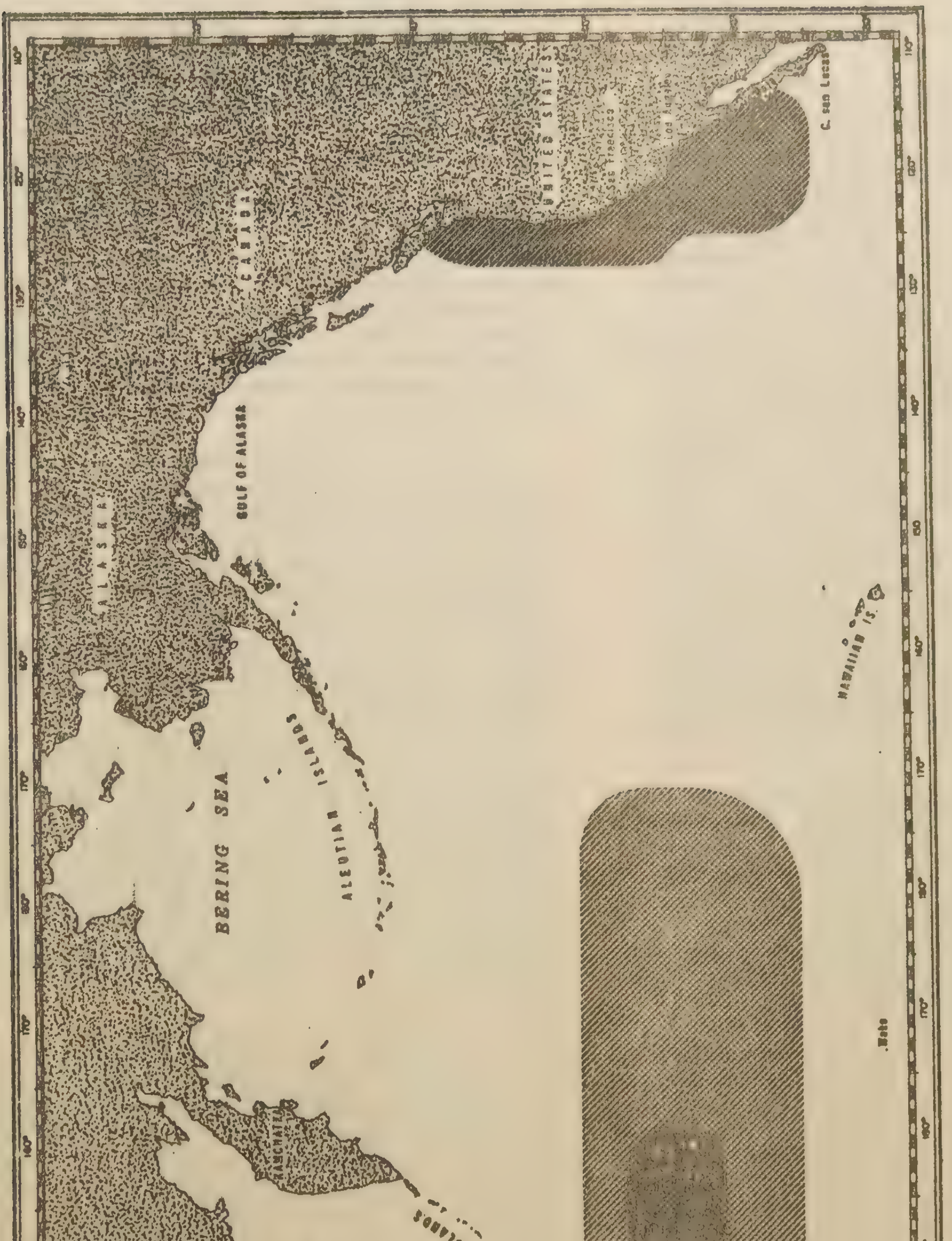
U.S.S.R.
SEA OF OKHOTSK
JAPAN SEA
JAPAN
KURIL ISLANDS
KAMCHATKA
BERING SEA
ALEUTIAN ISLANDS
ALASKA
GULF OF ALASKA
CANADA
UNITED STATES
San Francisco
Los Angeles
C. San Lucas
HAWAIIAN IS.
Wake

Fig. 1 Principal albacore fishing grounds in the North Pacific. The Japanese coastal fishery (spring and summer) is in black; their longline fishery (fall and winter) is outlined with diagonal lines. The American fishery (summer and fall) is marked with diagonal lines.

3 GENERAL ALBACORE MIGRATIONS

3.1 Migration of mature albacore (ages V+)

Most mature albacore are five years old (93 cm) and older (Ueyanagi, 1957; Otsu and Uchida, 1959). These adults move downward from the ocean's surface layers as they reach these ages and eventually populate a vast region well-beneath the sea -- many are caught at 70 to 80 fathoms. They inhabit the northern part of the Kuroshio Current, the North Pacific Current, the North Equatorial Current and the Equatorial Countercurrent areas between the longitudes of the Hawaiian Islands and Japan (Suda, 1956). Mature adults in the Kuroshio and North Pacific Current areas and those approaching first maturity undertake a southward migration each autumn and winter into the North Equatorial Current and Equatorial Countercurrent regions and joint those that remained there the previous season. Their migration coincides with the seasonal progress of the so-called Polar Front and the Sub-tropical Convergence; both move south in the autumn and winter and northward in the spring and summer (Nankai Regional Fisheries Research Laboratory, 1954).

Although some spawning may occur farther north, most takes place at considerable depth in the environs of the North Equatorial Current and the Equatorial Countercurrent during a comparatively short interval within the period January to June inclusive. The eggs are liberated in the oxygen-rich layers overlying the thermocline, in temperatures warmer than 14° C (57° F). After spawning, a few adults linger in the general area but most of the schools begin a gradual northward migration and disperse widely. The migration takes place mainly during July, August and September. By September, fair numbers of adult albacore have appeared once again in the Kuroshio and North Pacific Current "assembly areas" as far north as the southern margin of the Subarctic Water mass. In October, they are concentrated in this region and another southward migration begins. It is well underway by November.

3.2 Migrations of immature albacore (ages I-IV)

An abundance of immature one- to four-year-old albacore accompany the mature adults moving southward each season. Young fish inhabit the surface layers to the north while the older ones travel somewhat deeper. Immature albacore part company from the adults which continue southward during March to cross the Sub-tropical Convergence region and enter the North Equatorial Current and Equatorial Countercurrent environments (Suda, 1956; Nankai Regional Fisheries Research Laboratory, 1959). Many of the immatures travel west and southwesterly and then swing upcoast through Japan's coastal fishery.

Some schools of immature albacore do not migrate up the Japanese coast but travel north in relatively shallow sea-surface layers and become widely distributed during April to August; in April and May, many schools separate from this group and migrate toward the American coast. The remaining immature albacore continue northward and, in August and September, join those that have moved eastward from Japan.

During September and October, many spawned-out adults that have been traveling northward more slowly and considerably deeper also arrive in this northern "assembly area". By November, albacore of all sizes are moving southward again (small fish near the surface and to the north and larger ones at depths and to the south), and the annual cycle is started again.

4 MIGRATION ALONG EAST-COAST JAPAN

Small numbers of albacore appear southeastward from Japan during March and April. By May, their numbers have increased and they begin to migrate northeasterly up the Japanese coast and then gradually turn eastward, moving in a band averaging 200 to 300 miles wide. The northern limit of albacore catches in this band is near 37° N latitude (Van Campen, 1960). In June, the albacore schools are quite concentrated and Japan's "coastal" fishery peaks. At this time, a preponderance of fish are more than 100 miles offshore. The migration continues eastward during June and July and by July the schools have become somewhat scattered; in August, live-bait fishing ends because most of the albacore are dispersed about 1,000 miles offshore.

During a Japanese east coast albacore run, age-III and IV fish are abundant; they travel at relatively shallow depths and are accompanied by some age-II and V fish, forming widely scattered schools. The younger fish travel nearer the Japanese coast than do the older ones. The coastal migration is highly variable and follows behind the seasonal advance of suitable sea temperatures and the Kuroshio Current. The Kuroshio weakens and declines in the autumn and winter; in the spring and summer it strengthens and moves northward again (Nankai Regional Fisheries Research Laboratory, 1954). The timing, rate of advance, and manner in which the warm Kuroshio moves northward exercise control on the coastal migration. During some years, the Kuroshio advance results in isolated water masses having suitable temperatures close to shore until the end of May or later (Van Campen, 1960). This slows the albacore migration, and affects their concentration and distribution. In other years, the Kuroshio is unusually early and the isolated masses of albacore water do not develop or are short-lived. The schools move offshore (northeastward) more rapidly.

5 MIGRATION FROM THE WESTERN INTO THE EASTERN PACIFIC

The albacore migration route, from the west-central Pacific into the American coastal fishing grounds, lies in the North Pacific Current area. It is transient and its position and width fluctuate with changing sea conditions. All of the factors or combinations of factors that influence wide-ranging and ocean-spanning albacore migrations have neither been identified nor measured, but available data show that sea temperature is of utmost importance (Clemens, 1957, 1959, 1961b; Radovich, 1960, 1961). Temperatures not only affect albacore distribution, but seasonal changes in sea temperature exercise a directional control on the migrations.

The northern border of the eastward migration route is, for practical purposes, the 14° C (57° F) surface isotherm while temperatures near 20° C (68° F) delimit its southern boundary. Seasonal sea-surface warming apparently is superimposed on the current systems in the area. It is evidenced by a northward advance of temperatures in the spring and summer and cooling by a southward progression in the autumn and winter (U.S. Hydrographic Office, 1948). The rate and manner of the movement of isotherms delimiting the migration route vary considerably within and between fishing seasons and serve to restrict and enlarge the route's width and to modify its form.

In general, when the onset of spring is late and the advance of sea-surface warming is slow the route lies to the south and heavy concentrations of fish move into the southern part of the American fishing grounds. An early spring and a rapid seasonal warming rate will place the migration route to the north and albacore move into the grounds farther upcoast.

The migration toward the American coast begins in the spring and consists of young fish (primarily age groups I, II and III) traveling rapidly through the surface layers in the northern portion of the constantly-shifting route where sea-surface temperatures are about 14° to 18° C (57° to 65° F). At the migration's peak (July), older fish (primarily ages III, IV and V) are traveling at somewhat greater average depths through the southern part of the migration route where surface temperatures are 19° to 20° C (66° to 68° F). The fish are never as concentrated during the incoming migration as they are on the fishing grounds.

The incoming (eastward) migration ends about mid-August and on the fishing grounds young fish are scattered in the surface layers in loosely-knit school groups. Older fish are more tightly schooled and travel in groups both near the surface and at depths. Young albacore, found in water of 14° to 18° C (57° to 65° F) during the eastward migration (Craig and Graham, 1961; Craig and Caneday, 1962), are most abundant in 16° to 18° C (60° to 65° F) water on the southern feeding grounds. Older fish that migrate eastward in somewhat deeper water where surface temperatures are 19° to 20° C (66° to 68°F) are most abundant beneath 19° to 21° C (66° to 70° F) surface layers on the fishing grounds. The temperatures at the depths where these large fish spend most of their time are similar to those near the surface. When food is scare at deeper levels, the large fish move into warmer surface layers in search of prey.

When albacore reach their preferred ocean temperature regime within our coastal fishery area, they do not randomly disperse throughout the thousands of square miles of inhabitable sea. Instead, they concentrate in certain regions and become almost completely absent in others. Foremost among the reasons for their abundance or scarcity in a particular area are such environmental factors as areas of upwelling or ocean storms which cause local and rapidly-changing temperatures both at the surface and in the depths, the location and abundance of desirable food organisms, etc. By early August, they have begun a northward advance following optimum temperature and other environmental conditions.

6 MIGRATION ALONG WEST-COAST AMERICA

During a typical American West-coast albacore run, age-II fish are abundant; they are accompanied by a few age-I fish and form widely-scattered schools in the northern part of the fishery. Four and five-year-old fish are less abundant, more tightly schooled, and usually are south of the young ones. Age-group-III fish associate with both younger and older ones. Young albacore (ages I, II and some of the III's) travel rapidly through the lighted surface layers and lead the migration upcoast; older ones are distributed both near the surface and in the denser, deeper levels bringing up the rear.

The route taken by these northward-migrating albacore also is variable (Clemens, 1955, 1961b). Between central Baja California and Point Conception, the route upcoast usually starts relatively close to shore and then moves seaward as the season progresses depending upon the timing, rate and manner of warming from the south. Above Point Conception, albacore journey northward in the relatively warm, blue, oceanic waters outside of the cold, green, coastal zone. When the south-north warming of the coastal sea surface is slow compared to the albacore northward migration rate, the boundary between the northern cold water and warmer southern water acts as a barrier and the albacore slow down and concentrate behind it or move offshore. In general, the schools are concentrated south of Point Conception and become more widely dispersed after passing the Point on their way northward.

A few of the albacore comprising the fishery south of Point Conception do not complete an upcoast migration; instead, in response to changing environmental conditions, they head south in the autumn to over-winter near Guadalupe Island and southward. These over-wintering albacore are primarily four to six years old and some may spawn in this area during the forthcoming spring.

7 MIGRATION FROM THE EASTERN INTO THE WESTERN PACIFIC

In some seasons, September fishing is good on schools scattered from central Baja California to the Columbia River. Also, during late September, a gradual westward migration begins in the northern part of the fishery (off Eureka, California and north). This exodus increases in magnitude during October and by late November and early December most of the albacore have headed offshore toward the Orient to arrive in the western Pacific during the winter. The route taken, similar to the incoming one, is variable. It lies mainly within the southward progressing 14° to 20° C (57° to 68° F) band of surface water and again the younger fish are in the cooler areas to the north -- they also may tend to travel farthest west.

Where spring and summer migration into the American grounds is rapid and deliberate, the autumn and early winter exodus is more gradual and erratic. Albacore are broadly scattered near the surface and at depths within the outbound route.

Transpacific albacore journeys are not disorganized, fortuitous events. They occur with such precision (Clemens, 1961b) that a controlling mechanism must be involved -- a mechanism that is not modified by vagaries in the oceanic climate. Although we have no proof, photoperiodism, involving the albacore's light-receptive "pineal apparatus", may explain the timing of annual wide-ranging migrations. Thus albacore would not depart on an ocean-spanning migration until receiving the correct length-of-daylight stimulus.

8 LARVAL AND JUVENILE OR AGE-0 ALBACORE MOVEMENTS

This is one of the weakest sections in the authors model, revealing that considerable research is needed if we are to advance our knowledge of albacore larvae and juveniles beyond mere speculation.

Although spawning occurs during several months and over a longitudinal area which may exceed 2,000 miles, spawning and hatching probably are heaviest in the spring (March - May) and peak about April. Newly-hatched albacore slowly and steadily move toward the surface layers: those in the North Equatorial Current drift toward the west while those in the Equatorial Countercurrent drift eastward. They are widely scattered horizontally (in a west-east direction) and vertically. In a few weeks, all the youngster are strongh enough to make headway against the currents and most travel slowly northward while continuing to ascend into the ocean's surface layers. The albacore's "pineal apparatus" (Rivas, 1953) may also play an important role at this time.

Young-of-the-year fish are spread over thousands of square miles of albacore habitat in the western and central North Pacific and in the summer they are still so small that only a few of the largest (fastest growing or earliest spawned) are captured by Japanese live-bait fishermen. These age-0 albacore (35 cm group) although present in offshore areas, are not vulnerable to deep-fishing Japanese longline gear used in the subsequent autumn and winter fishery and rarely cross the Pacific to enter American coastal areas.

9 AGE-I ALBACORE MOVEMENTS

When albacore are 12 months old (in the spring) they average 52 cm fork length At this time, a few move westward and make a very small contribution to the Japanese spring and summer coastal fishery. Some of the largest swing eastward and commence their far-ranging (west-east) migrations, accompanying older groups that will comprise the American summer and autumn fishery. Most however, move northward scatter along the northern and cooler portion of the westerncentral North Pacific albacore habitat, and then proceed southerly to appear in the Japanese autumn and winter fishing areas.

The Age-I albacore that move through the American fishery head back across the ocean in the autumn and winter the west-central Pacific during the winter. In this area, they join the one-year-old albacore that remained and those that had traveled westward toward Japan and returned. All migrate south and soutwestward during the autumn and winter but they contribute only a small percentage to the longline catch.

The southerly migration ceases in March when some of the albacore turn west and northwesterly and then swing north and east through the Japanese coastal area. Small numbers appear in the Japanese spring and summer fishery as two-year-olds; most, however, turn northward. In the spring, a large portion breaks off from this group and, as two-year-olds, they rapidly migrate toward the American coast. The remaining albacore continue north and join those that migrated eastward from Japan in the late summer and autumn.

10 AGE-II ALBACORE MOVEMENTS

Although age-II albacore have served as the American fishery's backbone for more than a decade, they usually are of little importance to the Japanese coastal fishery and play a relatively minor role in their longline catch. Two-year-olds are highly vulnerable to surface trolling gear and usually contribute more than 60 percent annually to the American catch.

After moving through the American fishery, age-II albacore that have escaped capture migrate back across the ocean in the autumn and enter the west-central Pacific. In this area, they join with small numbers that had previously moved in from Japan and the somewhat larger numbers that had remained. This combined group lends a fair degree of stability to the presence and numbers of age-II fish in the southward-progressing autumn and winter longline fishery. By comparison, the numbers of two-year-olds in Japan's coastal fishery fluctuate widely from year to year because seasonally-varying proportions of them move into the coastal area from the west central Pacific.

After traveling southward in the longline fishery, age-II albacore swing to the north and then move eastward during the spring to reenter the American fishing grounds as three-year-olds. They may be accompanied by some age-III fish that did not make the trip as two-year-olds.

11 AGE-III ALBACORE MOVEMENTS

In comparison to age-II fish, the proportion of three-year-olds entering the American fishing grounds fluctuates widely from season to season. During some years, age-III albacore are almost entirely lacking while during others they are extremely important in our troll and live-bait fishery. When Age-III albacore return to the west-central Pacific from the American grounds, they join those that had entered the "assembly region" from the Japanese coastal fishery and large numbers that had remained in the area. These three-year-olds then contribute a substantial and dependable catch to the ensuing longline fishery. Typically, relatively small numbers of age-III albacore move into the eastern Pacific; instead, sizable quantities remain in the western Pacific and enter the Japanese coastal grounds which thus receive a larger and more stable number of age-group-III fish, by comparison with two-year-olds.

Age-three albacore are highly vulnerable to live-bait and longline fishing and rank among the most important age-groups in the western Pacific. Although there is much seasonal variation, small but significant numbers reenter the American fishing grounds as four-year-olds.

12 AGE-IV ALBACORE MOVEMENTS

Age-group-IV albacore enter the American fishing grounds somewhat later than the younger fish and are harvested by live-bait fishermen -- typically there are fewer of them than three-year-olds. Most of the age-IV albacore remain in the western Pacific, and together with the age-III fish, migrate through the two Japanese fisheries in the usual pattern and comprise a majority of the catch.

13 AGE-V AND OLDER ALBACORE MOVEMENTS

Only small quantities of five-year-old albacore appear in the American or Japanese coastal fishing grounds, but substantial numbers are taken in the Japanese longline fishery. Most become mature while in the west-central Pacific and head southward into deeper levels where they spawn for the first time. A few age-five albacore will overwinter in the eastern Pacific where they mature and spawn the following spring.

Six-year-old and older albacore also are not numerous in the coastal areas on both sides of the ocean. Instead, they remain with most of the age-V fish in the west-central North Pacific where they seasonally move south and north, into and away from the spawning grounds. Some remain in the general spawning region.

14 DISCUSSION

Albacore in the North Pacific undertake a variety of journeys; they migrate back and forth between the western and eastern sectors of the ocean and travel extensively, at constantly-varying depths, within and between many of the current systems. Migration timing may be controlled by photoperiodic stimulation, while the rate and direction of albacore movements are continually modified by differences in their ages, sizes, and state of sexual-maturity and by the seasonally-changing and widely-fluctuating oceanic environment.

Albacore of various ages are likely to take several combinations of long and short journeys in their travels but their general movement pattern seems to remain fairly stable. During certain seasons super-abundant year-classes at age-I have been detected and subsequently their impact as they moved through the American fisheries over a four-year period have been observed.

Although the obvious albacore journeys are those covering great distances and taking place between the major north Pacific fisheries, their vertical movements, that occur while the other travels are in progress, are equally important. Albacore hatch at depths and slowly move up into the ocean's surface lens, where they remain until attaining the age of three. At that time, they start moving into deeper levels and most have returned to the depths by the time they are six -- older albacore rarely are found near the surface.

Much of the albacore spawning area lies in the western north Pacific south of the Subtropical Convergence (Suda, 1958). Although running-ripe adults never have been captured, albacore larvae probably have been taken in numbers. Scientists studying tuna larvae, however, are finding it difficult to identify albacore with certainty. Only small quantities of age-zero albacore are captured in the North Pacific even though they are present in tremendous numbers in the western half. They are scarce in the catch because they are widely scattered and the fishing gear in use (live-bait and longline gear) is not suitable for taking them.

Large age-I albacore appear in catches of all the north Pacific fisheries; they occur in small quantities and average 54 to 58 cm fork length. Age-I and II albacore (52 and 65 cm respectively) contribute more to the American catch than the Japanese. They are widely-scattered while offshore from the fishing grounds and although they become more concentrated on the grounds, most remain loosely schooled and well-dispersed in the ocean's surface lens. Thus, young albacore are captured most efficiently by surface-trolling gear.

Age-III albacore (76 cm) contribute heavier to the Japanese fisheries -- especially the coastal -- than the American. They may be abundant in the west-central Pacific during the spring and summer but not many are harvested because the schools are well-dispersed and because longline gear does not capture age-III fish as efficiently as live-bait gear. They are considerably more abundant in the west-central Pacific during the autumn and winter.

Age-IV albacore (85 cm also contribute heavier to the Japanese fisheries than the American; they may be as abundant (although less concentrated) in the west-central Pacific as they are in the Japan coastal areas during the summer months. During the autumn and winter, however, their greatest numbers are in the west-central Pacific.

Age-V albacore (93 cm) and older are caught almost exclusively by the Japanese longline fishery and they are most abundant in the west-central Pacific region all year. Longline gear is efficient for harvesting the older groups inhabiting deeper ocean levels; however, when fished at depths in the American fishery it produces only small and medium-sized fish comparable to those in the surface catches.

Although the Japanese coastal fishery peaks in June and the American fishery peaks two months later (August), there is no direct migration between the two. Some fish may, however, travel from Japan through the autumn and winter longline fishing area and then enter the American grounds the following summer -- a one-year-old albacore departing from Japan would thus reach the American coast at age-II, a two-year-old at age III, etc.

Age-III and IV albacore typically are among the most abundant (numerically) and most stable of the age groups in the Japanese fisheries; by comparison their numbers fluctuate widely in the American catch -- especially those age-III. Age-III albacore may be scarce in the American fishery during some years because most had traveled toward Japan from the west-central Pacific. If a good year-class were known to exist, a poor showing of age-III albacore in the Japanese catch during its June peak could mean that relatively large numbers either had remained in the west-central Pacific or had headed toward the American grounds. Even though one can expect large variations, a June estimate of age-III albacore abundance in Japan's live-bait catch may give American biologists a clue as to how much of a contribution to expect from these 20-pounders during the forthcoming season. In addition, a superabundance of age-II albacore in the American fishery would put an extra-large number in the western or mid-Pacific during the autumn and winter. Since longline gear does not harvest age-II albacore efficiently, their great abundance could go undetected. During the forthcoming spring and summer, extra large numbers of these albacore, which by then would be three-year-olds, probably would hit the Japanese coastal fishery. Thus, a superabundance of age-II albacore in the American fishery may indicate larger-than-average numbers of age-III fish in the Japanese coastal area one year later.

From the overwhelming evidence obtained in the eastern North Pacific concerning the relationships between sea temperatures and albacore availability and migrations, the author believes that temperature (at or near the surface and in the depths) is a dominant environmental factor controlling albacore behavior throughout the Pacific. These data can be used to assist fishermen in locating areas that are most likely to produce fish of desirable sizes once the albacore "run" has begun and to anticipate the general area and depth where a "run" will occur. In addition, photoperiodism may control albacore migration timing. Thus the date an albacore run will hit our fishery could be predicted with accuracy.

These are but a few ways one can use a migration model to guide research planning and to improve understanding of a species so it can be fully and efficiently utilized. Plans are being made to improve this prototype migration model at every opportunity and to make the knowledge thus gained available to all who are interested.

Experience Paper No. 32

ESPECIES DEL GENERO Sarda EN EL PACIFICO ORIENTAL

por

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Extracto

Se ofrece una discusión, basada en los antecedentes de la validez de las especies del género Sarda en el Pacífico Oriental, destacándose el valor de determinados caracteres, para separar la identidad de las mismas.

Quedan después de las evaluaciones dos especies bien definidas: Sarda chilensis (Cuvier y Valenciennes, 1831) y Sarda velox Meek y Hildebrand, 1923. Estas dos especies se distinguen principalmente por la construcción del arco branquial y el número de dientes en la mandíbula inferior.

Sarda chilensis es propio de aguas templadas y S. velox ocurre en aguas tropicales.

Los recuentos vertebrales y análisis biométricos efectuados en S. chilensis señalarían, en esta especie, la tendencia a formar categorías taxonómicas menores.

SPECIES OF THE GENUS Sarda IN THE EASTERN PACIFIC

Abstract

The validity of the species of the genus Sarda in the Eastern Pacific is discussed. The discussion is based on an evaluation of previous determinations, and the value of some of their specific characters is pointed out.

As a result of the evaluation, two well-defined species are recognized: Sarda chilensis (Cuvier and Valenciennes, 1831) and Sarda velox Meek and Hildebrand, 1923. These two species are mainly distinguished by the construction of the branchial arch and the number of teeth on the lower jaw.

Sarda chilensis is found in temperate, and S. velox in tropical waters.

Vertebrae counts and biometric analysis of S. chilensis indicate a probable tendency of the species towards subspecific fragmentation.

LES ESPECES DU GENRE Sarda DU PACIFIQUE ORIENTAL

Résumé

L'auteur examine la validité de la subdivision en espèces du genre Sarda du Pacifique oriental, en se fondant sur l'évaluation des diagnoses antérieures, et met en relief l'intérêt que présentent certaines des caractéristiques relevées.

L'évaluation permet de distinguer 2 espèces bien définies: Sarda chilensis (Cuvier et Valenciennes, 1831) et Sarda velox Meek et Hildebrand, 1923, qui se différencient principalement par la structure des arcs branchiaux et le nombre des dents de la machoîre inférieure.

Sarda chilensis habite les eaux tempérées et S. velox les eaux tropicales.

D'après le dénombrement des vertèbres et l'étude biométrique, l'espèce S. chilensis aurait tendance à se scinder en sous-espèces.

1 ESPECIES DEL GENERO Sarda EN EL PACIFICO ORIENTAL

1.1 Sus relaciones

Tres especies de Sarda se han reconocido en este lado del Pacífico: Sarda chilensis, Sarda lineolata y Sarda velox.

Walford (1936) da para estas especies la siguiente clave:

"a) Branquiespinas en la parte inferior del primer arco de 15 a 18; líneas negras, paralelas, oblicuas o raramente horizontales en la parte superior de los lados.

b) La aleta pectoral no llega al borde posterior del corselete....lineolata

bb) La aleta pectoral sobrepasa el borde posterior del corselete por lo menos por el diámetro de un ojo....................chilensis

aa) Branquiespinas en la parte inferior del primer arco, en número de 9; líneas negras, horizontales en la parte superior de los lados velox"

Aparte del carácter de la construcción del arco branquial, los otros caracteres citados en esta clave, son muy discutidos.

Godsil (1954, 1955), después de un estudio detallado y comparativo de las especies del género Sarda, para la evaluación de los caracteres externos y anatómicos que individualizan a cada especie, encuentra lo siguiente:

Entre lineolata y velox, las bandas horizontales u oblicuas no pueden ser consideradas como un carácter de diagnóstico positivo. El ha encontrado ejemplares de lineolata con las rayas oblicuas en un lado y en el otro casi horizontales.

En lineolata los dientes, aunque largos y agudos, son más pequeños que los de velox; en la mandíbula inferior se encuentran aproximadamente 20 a cada lado, mientras que en velox se encuentran 12; este carácter, dice, puede ser adicionado al número de branquiespinas para separar estas especies. Con respecto a las diferencias vertebrales, encuentra que el promedio en lineolata está representado por 23 precaudales más 22 caudales, y el promedio en velox, por 24 precaudales más 21 caudales, aunque ambas caen en el rango de 44 a 46 vértebras.

Y en cuanto a la separación efectuada por Walford entre lineolata y chilensis, a base de la dimensión del corselete, no es corroborada por los análisis de Godsil, ya que en las comparaciones por él efectuadas no encuentra tal diferencia y concluye que no existe suficiente fundamento para considerar como válidas dos especies, las mismas que pueden ser reducidas a una sola que tendría el nombre de chiliensis (= chilensis) por ser el que tiene prioridad.

Por experiencia personal, igualmente considero que en la separación de chilensis y velox no tendría valor la disposición de las líneas, ya que chilensis presenta las líneas oblicuas u horizontales sobre el dorso indistintamente. También las cuentas de los dientes de la mandíbula inferior, en esta última 20 a 25, coinciden con las efectuadas por Godsil (de Vildoso, 1958).

Y en cuanto a la dimensión del corselete, en muchas de las especies examinadas, es imprecisa y su relación con la pectoral no siempre puede determinarse. También Hildebrand (1946) ha señalado anteriormente este punto.

Estos datos corroborarían la invalidez de Sarda lineolata, como especie.

Quedan, pues, para el Pacífico oriental dos especies cuya identidad es clara: chilensis y velox separadas, netamente, por el número de branquiespinas y el número de dientes en la mandíbula inferior.

En los estadios juveniles de Sarda, Pinkas (1961) ha establecido que, a partir de las tallas de 24 mm., se pueden diferenciar S. chilensis y S. velox por las siguientes características:

Quadro I

Características de los estadios juveniles de *S. velox* y *S. chilensis*

Especies	No. Branquiespinas: Totales	No. dientes maxilar inferior	Dientes faringeales
Sarda velox	11 - 14	Irregulares 12 - 15	Rudimento
Sarda chilensis	19 - 27	Uniformes 14 - 25	Numerosos y bien desarrollados

Además de los caracteres de diágnostico citados, existen otros menos aparentes, que describe Godsil (1955). El considera todas las especies de género *Sarda* conocidas en el mundo: *S. sarda*, *S. chilensis*, *S. orientalis* y *S. velox*, divididas en dos grupos básicos que constituirían los complejos *sarda* - *chilensis* y *orientalis* - *velox*, con los caracteres enumerados en la Quadro II.

De Buen (1958), apoyándose en el criterio de Godsil (1955), considera que en el mundo sólo existen dos especies de *Sarda*: *S. sarda* y *S. orientalis*. La primera cuyas subespecies serían *S. sarda sarda* y *S. sarda chilensis*, y la segunda con las subespecies *S. orientalis orientalis* y *S. orientalis velox*. Las apreciaciones de de Buen (1958) parecen tener un fundamento lógico; pero, por otra parte, no he realizado una revisión total de la literatura del grupo, ni he tenido oportunidad de comparar material de todas las especies en discusión; por ello, provisionalmente, prefiero seguir considerando en el Pacífico oriental las especies *Sarda chilensis* y *S. velox*.

1.2 *Sinonimia* (Tomada de Hildebrand, 1946, y de Buen, 1958)

Para *Sarda chilensis* (Cuvier y Valenciennes):

Pelamys chilensis	Cuvier, en Cuvier y Valenciennes 1831, p. 163 (primera descripción).
Pelamys chilensis	Guichenot, en Gay 1948 Günther 1860, p. 168. - Reed 1897, p. 660 - Delfin 1899, p. 58 - Gotschlich 1913, p. 198 - Quijada 1913, p. 41
Pelamis chilensis	Delfin 1899
Sarda chilensis	Abbott, 1899, p. 345, Delfín 1902, Starks 1906, p. 784 - Evermann y Radcliffe, 1917, p. 55. - Nichols y Murphy 1922 - Meek y Hildebrand, 1923 p. 318. - Fowler 1945 - Hildebrand 1946 p. 372.
Sarda sarda chiliensis	De Buen 1958, p. 12

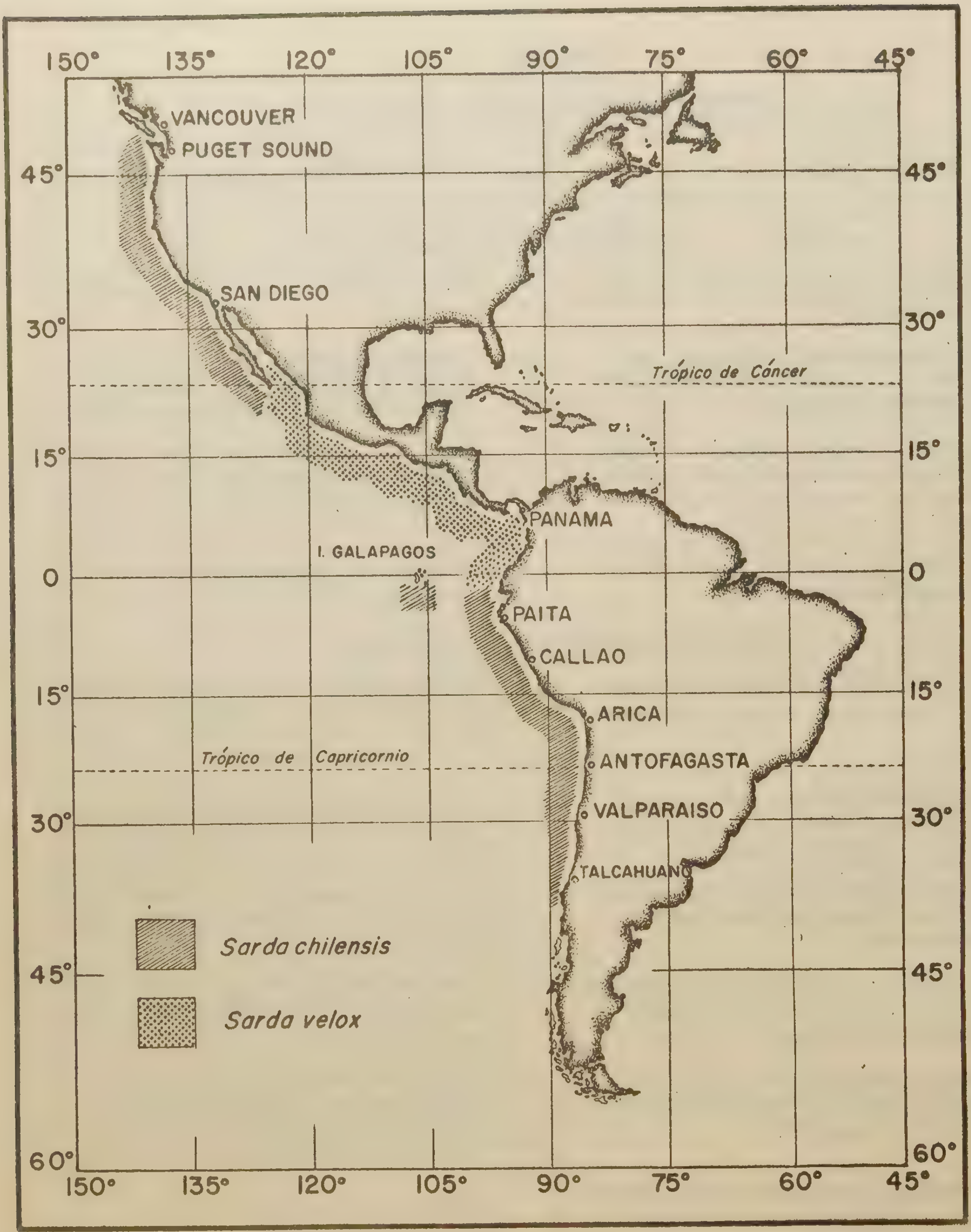
Para *Sarda velox* (Meek y Hildebrand):

Sarda chilensis	Gilbert y Starks (no de Cuvier y Valenciennes) 1904, p. 68
Sarda velox	Meek y Hildebrand 1923, p. 320 - Walford, 1937 - Schmitt y Schultz 1940, p. 3
Sarda orientalis velox	De Buen 1958, p. 12

Quadro II

Caracteres de las especies según Godsil (1955)

Sarda chilensis	orientalis velox
Caracteres superficiales	
1 Dientes desarrollados en el primer arco branquial.	1 No hay dientes desarrollados en ningún arco.
2 Porción posterior del maxilar en forma de V, maxilar suplementario tan ancho como largo.	2 Porción posterior del maxilar en forma de V, maxilar suplementario la mitad del ancho con respecto al largo.
3 De 7 a 10 branquiespinas en la parte superior del primer arco (excluyendo las situadas en el ángulo del arco). Cuenta total: 20 a 27.	3 De 2 a 4 branquiespinas en la parte superior del primer arco (excluyendo las situadas en el ángulo del arco). Cuenta total: 8 a 15.
4 De 20 a 25 dientes a cada lado de la mandíbula inferior.	4 De 10 a 15 dientes a cada lado de la mandíbula inferior.
Caracteres superficiales corroboratorios	
5 Longitud de la cabeza entre longitud del maxilar igual a: 1, 86 a 1, 93.	5 Longitud de la cabeza entre longitud del maxilar igual a: 2, 05 a 2, 18.
Esqueleto	
6 Glosohyal tiene una corta depresión longitudinal sobre la superficie ventral de la porción proximal.	6 Al glosohyal le falta este surco y la cara del hueso es convexa hacia afuera.
7 Maxilar suplementario: máxima longitud entre ancho máximo igual a: 3, 00 a 3, 83.	7 Maxilar suplementario: máxima longitud entre ancho máximo igual a: 4, 01 a 4, 50.
8 Clavícula se proyecta posteriormente cerca de la mitad de su longitud y se aplana distalmente.	8 Clavícula se proyecta posteriormente con un ancho aproximadamente uniforme.
9 Espina hyomandibular se proyecta posteriormente, del cóndilo central se curva hacia arriba.	9 Espina hyomandibular se proyecta posteriormente, del cóndilo central se curva hacia abajo o por lo menos perpendicularmente.
10 La columna vertebral puede ser positivamente identificada por comparación directa de sus procesos ventrales. Las hemapófisis, a partir de la 10ª vértebra, se proyectan hacia atrás.	10 Las hemapófisis, a partir de la 10ª vértebra, se proyectan hacia adelante



150°
135°
120°
105°
90°
75°
60°
45°
0
15°
30°
60°
VANCOUVER
PUGET SOUND
SAN DIEGO
Trópico de Cáncer
PANAMA
I. GALAPAGOS
PAITA
CALLAO
ARICA
Trópico de Capricornio
ANTOFAGASTA
VALPARAISO
TALCAHUANO
Sarda chilensis
Sarda velox

Fig. 1 Distribución geográfica del género Sarda en el Pacífico Oriental (Tomado de: de Vildoso 1955)

1.3 Distribución geográfica

S. chilensis ocurre desde Canadá (Vancouver) a Chile, aunque en forma discontinua; aparentemente es propia de las zonas templadas.

En el hemisferio norte sus centros de mayor distribución están entre Punta Concepción y Bahía Magdalena y en el hemisferio sur de Paita (Perú) a Talcahuano (Chile).

Las áreas de mayor pesca en el Perú comprenden de Chimbote a Pisco, y en Chile, entre Antofagasta y Arica.

En el tramo de costa comprendido entre Bahía Magdalena y el Perú han constatado su presencia en ocasiones aisladas; en las Islas Galápagos (Fowler, 1938).

Sarda velox se encuentra desde Bahía Magdalena en Baja California a Cabo Blanco, en el norte del Perú, aunque los registros son discontinuos. Schweigger (1959) también la cita para las Islas Galápagos. Esta especie también ha sido registrada en la Isla Block en el Atlántico, según Breder, 1923, p. 31 (en Hildebrand 1946, p. 375).

No se conoce exactamente la distribución de los bonitos Sarda en el sentido de la longitud, pero aparentemente son pelágicos costeros, siendo reemplazados en el pelagial oceánico por atunes y barriletes que realizan desplazamientos de mayor alcance; esta presunción está respaldada por las pesquerías y por la determinación de sus hábitos alimenticios. Durante los meses de temporada de pesca, que coincide con su época de reproducción, las capturas de S. chilensis en el hemisferio sur rara vez se realizan más allá de las 30 millas, aunque Schweigger (1959) da su distribución hasta las 60 y 80 millas. En el hemisferio norte se han encontrado sus huevos hasta a 80 millas de la costa (Walford, 1937).

Durante los meses de invierno están poco disponibles para la pesquería y no se conoce a dónde emigran.

1.4 Categorías infraespecíficas y estudios raciales

Si las especies del género Sarda constituyen categorías taxonómicas menores es un interrogante, los estudios a continuación indicados señalan una tendencia.

Vildoso (1959) en un estudio de cuentas vertebrales compara dos muestras de bonito S. chilensis de la zona de Callao; una de 38 ejemplares obtenidos de noviembre de 1957 a marzo de 1958, y otra de 100 ejemplares obtenidos de abril a noviembre de 1958, éstas con una muestra de S. chilensis del hemisferio norte, consistente en 19 ejemplares, considerando en conjunto el material de Clothier (1950) y el de Godsil (1954).

Vildoso encuentra para los ejemplares del Callao los promedios vertebrales de 44,15 con desviación "standard" de 0,40 y de 44,21 con desviación standard 0,50 para las muestras de 38 y 100 ejemplares respectivamente, y para los ejemplares del hemisferio norte un promedio de 45,0 con desviación standard de 0,47. Los promedios de los del Callao fueron encontrados significativamente diferentes del correspondiente a los bonitos del norte, satisfaciendo la regla llamada del "75 por ciento" para separación de unidades taxonómicas.

Esto indicaría que el número vertebral tiene validez estadística para una separación. Según Vildoso (comunicación verbal), ésta es de categoría subespecífica, criterio que comparto de acuerdo con sus resultados y propondría que las subespecies se denominaran S. chilensis lineolata y S. chilensis chilensis, en los hemisferios norte y sur respectivamente.

Gifford (1957) inició un estudio racial de S. chilensis con muestras procedentes de Chimbote, Callao e Ilo, a base de análisis biométrico. Las medidas analizadas fueron: longitud de la cabeza, prepectoral, preventral, predorsal y preanal, relacionadas con la longitud a la horquilla.

Los resultados alcanzados por cada localidad fueron:

Chimbote: diferencia significativa entre machos en predorsal y preanal, y en las hembras en prepectoral, predorsal y preanal.

Callao: diferencia significativa entre hembras y machos en cabeza, prepectoral, predorsal y preventral.

Ilo: diferencia significativa entre machos y hembras en la prepectoral, en los machos en todas las medidas excepto preanal y en todas las hembras en cabeza, prepectoral, preventral y preanal.

En el análisis de las diferencias entre las localidades se encuentra significación para las hembras en todas las medidas.

Es decir, que hay indicios de que en Chimbote, Callao e Ilo, los bonitos S. chilensis constituyen poblaciones independientes, y que en Ilo el grado de hetereogeneidad es mayor.

Por otra parte, medidas de las longitudes de los bonitos en el Callao (Perú) y en Chile, muestran diferencias en promedio; al parecer, las tallas promedios de los bonitos en Chile son superiores. Cabe aquí la posibilidad de que se trate de dos poblaciones con diferente ritmo de crecimiento, o de una sola en la que los integrantes de mayor dimensión se sitúan hacia la región geográfica sureña.

Ninguno de estos resultados es todavía concluyente; sería necesario poseer mayor información al respecto, porque aunque Gifford (1958) ha seguido los procedimientos estadísticos clásicos para la diferenciación de poblaciones por análisis biométricos y ha encontrado validez estadística para una separación, no está demostrado si estas diferencias son transitorias o se mantienen a través del tiempo.

Estudios en los atunes, albacoras, caballas, han demostrado que tienden a formar "stocks" independientes o poblaciones, en el área de su distribución, y es probable que lo mismo ocurra en los bonitos Sarda.

Experience Paper No. 33

DISTRIBUTION AND ABUNDANCE OF TUNA RELATED TO WIND AND OCEAN CONDITIONS IN THE GULF OF TEHUANTEPEC, MEXICO

By

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Abstract

The Gulf of Tehuantepec is exposed to northerly winds which blow consistently in winter. They cause a circulation which results in an undulating pycnocline topography; they also stir the upper part of the pycnocline in the area of its greatest elevation, where eutrophication results. It was hypothesized that yellowfin are more abundant in this area and season than in any other in the Gulf, by reason of their aggregation upon the expected high concentrations of their prey.

This hypothesis was tested by analysis of variance of logged means of yellowfin catch per day by baitboat, classified by areas, years, and seasons. It was not confirmed in its original form, but it was confirmed when the assumption of an average lag of three months between wind action and resulting crop of small nekton (yellowfin food) was made; i.e., the expected differences between areas occur in spring instead of winter. No differences were found between years, despite much variability in surface temperature over the period studied: average in 1953, low in 1954 to 1956, and high in 1957 to 1959. The same pattern of yellowfin distribution could therefore be expected from year to year in the spring months.

A similar analysis of contemporaneous skipjack data gave an entirely different result: only differences between years were significant, with catch per day highest in cool years and very low in warm years.

DISTRIBUTION ET ABONDANCE DU THON EN FONCTION DES CONDITIONS DU VENT ET DE LA MER DANS LE GOLFE DE TEHUANTEPEC, MEXIQUE

Résumé

Le Golfe de Tehuantepec est exposé à des vents du Nord qui soufflent assez fortement en hiver. Ils provoquent une circulation qui se traduit par une topographie condulante de la pycnocline; ils mélangent également la partie supérieure de la pycnocline dans la zone de sa plus grande élévation, avec une eutrophication en conséquence. On a supposé que les thons à nageoires jaunes seraient plus abondants dans cette zone et au cours de cette saison que partout ailleurs dans le golfe, parce qu'ils se rassembleraient autour des fortes concentrations attendues de leur proie.

Cette hypothèse a été étudiée par l'analyse de la variance des moyennes relevées des quantités de thons à nageoires jaunes capturées par jour et par bateau pêchant à l'appât vivant, classées par zones, années et saisons. L'hypothèse n'a pas été confirmée sous sa forme originale, mais elle s'est trouvée vérifiée quand on a supposé qu'un délai moyen de trois mois s'écoulait entre l'action du vent et le développement résultant d'un petit nekton (nourriture du thon à nageoires jaunes); c'est-à-dire que les différences attendues entre les diverses zones se présentaient au printemps et non en hiver. On n'a pas trouvé de différence entre les années malgré la variabilité élevée de la température de surface au cours de la période de l'étude: moyenne en 1953, faible en 1954-1956 et haute en 1957-1959. On peut s'attendre en conséquence à ce que la distribution du thon à nageoires jaunes présente une allure comparable d'année en année au cours du printemps.

Une analyse identique des données parallèles concernant la bonite à ventre rayé a donné une conclusion entièrement différente: seules les différences d'une année à l'autre étaient significatives, avec des pêches journalières élevées au cours des années froides et très faibles au cours des années chaudes.

DISTRIBUCION Y ABUNDANCIA DE ATUNES CON RELACION A LAS CONDICIONES DEL VIENTO Y EL OCEANO EN EL GOLFO DE TEHUANTEPEC, MEXICO

El Golfo de Tehuantepec está expuesto a los vientos del norte que soplan constantemente durante el invierno y causan una circulación que da por resultado una topografía picnoclina ondulante; agitan también la parte superior de la picnoclina en su área de mayor elevación, lo que da por resultado una eutroficación. Se sustentaba la hipótesis de que el atún de aleta amarilla es más abundante en esta zona y época que en cualquier otro lugar del Golfo, debido a su congregación en las esperadas concentraciones altas de sus presas.

Esta hipótesis se ensayó por análisis de las variaciones de las medias de los registros de pesca de atún de aleta amarilla por día y barco con vivero, clasificadas por zonas, años y estaciones. No se confirmó en su forma original, pero sí cuando se supuso que existía un retardo medio de tres meses entre la acción del viento y la cosecha resultante de nekton pequeño (el alimento del atún de aleta amarilla), es decir, las diferencias esperadas entre zonas ocurren en primavera en vez de en invierno. No se observaron diferencias entre los años a pesar de la mucha variación de la temperatura de la superficie en el período estudiado: normal en 1953, baja en 1954-1956 y alta en 1957-1959. Debido a ello podría esperarse la misma modalidad de atún de aleta amarilla de un año a otro en los meses de primavera.

Un análisis análogo de datos contemporáneos del barrilete dio resultados totalmente distintos; sólo tenían importancia las diferencias entre años, siendo las capturas diarias mayores en los años fríos y muy bajas en los cálidos.

1 INTRODUCTION

The purpose of this paper is to show how far existing knowledge of oceanic and atmospheric conditions can explain spatial and temporal differences in distribution and abundance of tuna in the Gulf of Tehuantepec, where there is a substantial fishery by United States nationals.

The published climatologic and oceanographic information is reviewed (sections 2 and 3); from this and other information it is hypothesized that certain patterns of tuna distribution occur at particular seasons of the year (section 4); data on catch per unit of fishing effort are analyzed statistically to test the hypothesis, which is confirmed in part for yellowfin tuna, *Neothunnus macropterus* (the principal species in the Gulf fishery), but not at all for skipjack tuna, *Katsuwonus pelamis* (section 5); it is shown in discussion that the hypothesis is entirely confirmed for yellowfin when amended in one reasonable particular, and that it has then some potential practical value for fishermen; for skipjack, the foundations of a different hypothesis are laid (see section 6).

The work was done at the Scripps Institution of Oceanography of the University of California, as part of the Scripps Tuna Oceanography Research (STOR) Program, with the support of the United States Bureau of Commercial Fisheries.

2 TOPOGRAPHIC AND CLIMATOLOGIC FEATURES OF THE REGION

The Gulf of Tehuantepec is a bight on the Pacific coast of southern Mexico, near Guatemala. It is bounded on the north by the Isthmus of Tehuantepec, which is one of the three parts of Central America that are both low and narrow; the others are in Nicaragua (lake region) and Panama (canal region). The Isthmus is about 220 km wide from north to south in its narrowest part, where the cordillera is cut by a pass some 40 km in width and 250 m in maximum elevation (Fig. 1).

Because of this topography the Gulf is exposed to weather from the Atlantic side of Central America. The same applies to the Gulfs of Papagayo and Panama, which are on the Pacific side of the other two regions of similar topography. Elsewhere along the central American isthmus, high mountains protect Pacific coastal waters from Atlantic winds.

Without this exposure, the Gulf of Tehuantepec would generally be subject to light to moderate trade winds in winter and light variable winds in summer, because of its location in relation to the seasonally fluctuating position of the Intertropical Convergence (Crowe 1952); the trade wind would probably blow from the northwest, as it does along the rest of the Pacific coast of southern Mexico (U. S. Navy Hydrographic Office 1949; Meteorological Office, London, 1956). Actually the winter wind regime is dominated by moderate to strong northerlies called Tehuantepecers, which occur through the formation of strong anticyclones over the North American plains and their extension into the Gulf of Mexico, with the winds increasing in velocity as they traverse the narrow pass on the Isthmus of Tehuantepec (U. S. Navy Hydrographic Office 1951). These conditions occur typically from October through April, when winds from the north are much more frequent than those from any of the other seven principal directions, with an average force of > 3 Beaufort (>10 knots); they are at peak from November through February, when northerlies are observed more frequently than winds from all other directions combined, with an average force of >> 4 Beaufort (>>16 knots); most of the other wind in the period October through April comes from the northeast or northwest (U. S. Navy 1955, 1959).

During the remaining months of the year, May through September, the winds are more variable (mainly from the north, east, west, and directions between) and weaker (average < 3 Beaufort), but occasional Tehuantepecers occur (U. S. Navy 1955, 1959).

3 OCEANOGRAPHIC FEATURES OF THE GULF OF TEHUANTEPEC

The Gulf of Tehuantepec lies in the region of warmest surface water in the eastern Pacific, but during the winter months some of this water is at least 1 °C colder than the rest. The area of cold surface water extends up to 400 miles in a south-southwesterly direction from near the head of the Gulf (which is in the longitude of the transisthmian mountain pass), with warmer water to the east and west. Details are available in monthly average charts (U. S. Navy Hydrographic Office 1944; Meteorological Office, London, 1956).

The fact that this cooling occurs at the Tehuantepecer season, and in the part of the Gulf most likely to be disturbed by these winds, suggested a cause-and-effect relationship between

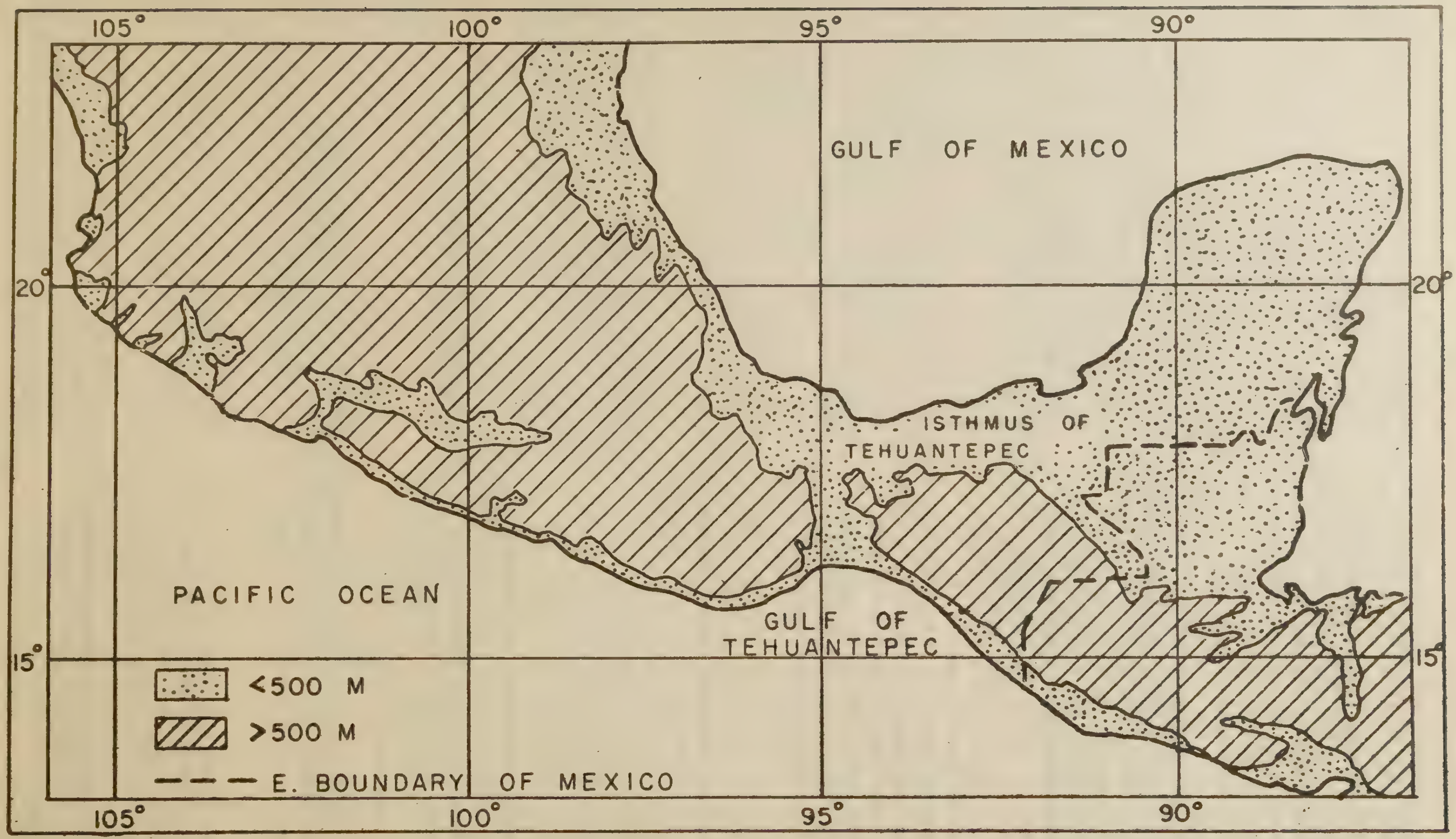

105°
100°
95°
90°
20°
15°
GULF OF MEXICO
ISTHMUS OF TEHUANTEPEC
PACIFIC OCEAN
GULF OF TEHUANTEPEC
<500 M
>500 M
E. BOUNDARY OF MEXICO

Fig. 1 Southern Mexico and adjacent regions, showing the Gulf of Tehuantepec in relation to the terrestrial topography and the Gulf of Mexico

wind and surface temperature, involving upward movement of subsurface water. This could be expected to enrich the surface waters chemically and permit them to become more productive biologically. These ideas prompted oceanographic studies of the region by Brandhorst (1958), Roden (1961), Blackburn (1962). The summary of oceanic conditions which follows is mainly that of Blackburn: it is based on a greater number and diversity of oceanographic observations than those used by the other authors, is consistent with most of their observations and conclusions, and is believed to present the most complete description and interpretation that can be given at the present time.

Average surface current charts for June, July, and August show a simple drift along this part of the coast, west-northwest through the Gulf of Tehuantepec (Cromwell and Bennett 1959). Pycnocline topography and horizontal distributions of properties would be expected to be rather uniform zonally; this is confirmed for surface temperature by published average charts (references above; also Roden 1961, Fig. 1b), but little other useful information is available about the region in those months.

Similar charts for the Tehuantepecer months, October through April, show a different surface circulation (Cromwell and Bennett 1959). The prevailing northerly winds cause a current to flow from the head of the Gulf to the south and southwest, whereby the previously described line of flow becomes sinuous in the general form of a letter S rotated 90° clockwise. This pattern can be transformed into the general form of a numeral 8 rotated 90° clockwise, i.e. with a clockwise eddy in the western half of the Gulf and an anticlockwise one in the eastern half; this might be associated with changes of wind from north to northwest, with corresponding changes in the current. In either case a characteristic pycnocline topography, with a ridge or dome in the eastern loop and a hollow or trough in the western, would be expected (Fig. 2).

Such current patterns and pycnocline topographies were found on oceanographic surveys made in November 1958 and January-February 1959, and also in May 1958 and September 1959 (Blackburn 1962). Their occurrence in May and September was not expected because average charts for those months show more variable winds than in any other months, and a surface circulation pattern somewhat intermediate between that of the period June through August and the period October through April. However, the May and September findings were consistent with moderate northerlies which were blowing at the times of observation. Conversely, one of the two surveys made in November showed only slight development of the above-mentioned features, consistent with the unusually calm conditions then prevailing; in the second November survey, which was made immediately after a strong northerly, the expected features were prominent.

On the crest of the ridge the top of the pycnocline was found from about 12 to 25 m below the sea surface, and in the bottom of the hollow it occurred from about 40 to 75 m below the surface; both elevations depend upon the velocity of the northerly wind and corresponding southerly current, the difference between the elevations being greatest when the current is strongest; current velocities, measured by geomagnetic electrokinetograph, were up to 2-1/2 knots.

As the pycnocline ridge approaches the windy sea surface, the upper part of the pycnocline is stirred by the action of wind-waves. The pycnocline is weakened but does not disappear. The properties of the surface layer above it become more like those of the pycnocline itself: e.g., lower temperature, higher salinity, and higher phosphate concentration. Production of biota is stimulated in near-surface waters, with surface primary production up to 161 mg. C/m.^{3}/day. These phenomena are best developed in the region where the ridge top is most affected by the wind, which is along the western shoulder of the ridge (Fig. 2; see Roden 1961, Fig. 3, for distribution of wind stress). Within that meridional belt they tend to be best developed near the middle of the Gulf, over 50 miles south of the Isthmus, despite the fact that wind stress is highest at the Isthmus; this is not clearly understood, although several explanations have been suggested.

Standing crop of small zooplankton was the most frequent biological property measurement made on the cruises. It was highest in the area of the southern part of the ridge or further west in the area of the hollow. Its concentration over the ridge is interpreted as an effect of secondary production in the partly destratified eutrophic area, in succession to high primary production; in the oligotrophic area of the hollow, it is interpreted as an effect of downstream displacement and possible concentration in the western eddy. The maximum concentration was of the

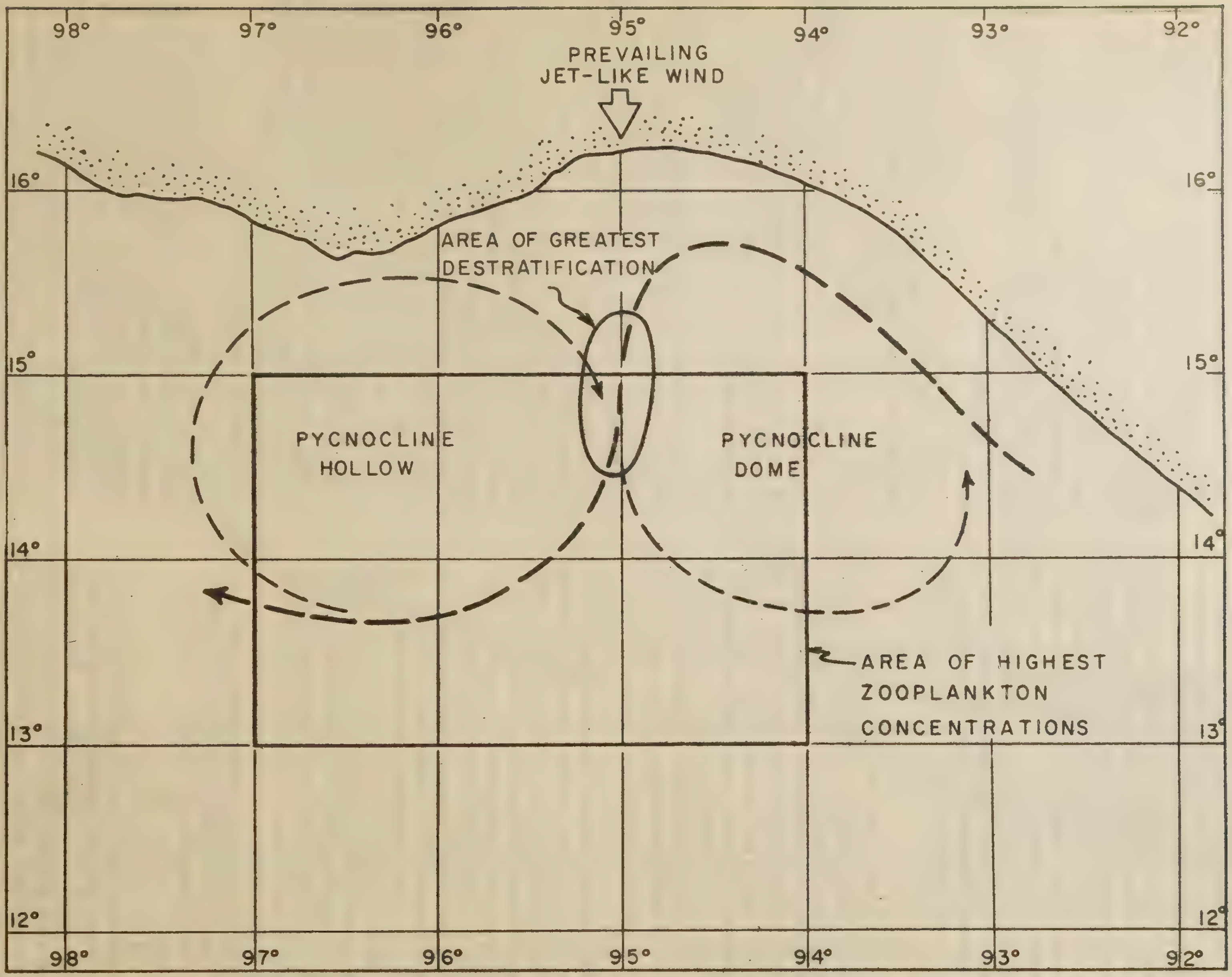

98°
97°
96°
95°
94°
93°
92°
PREVAILING
JET-LIKE WIND
16°
15°
14°
13°
12°
AREA OF GREATEST
DESTRATIFICATION
PYCNOCLINE
HOLLOW
PYCNOCLINE
DOME
AREA OF HIGHEST
ZOOPLANKTON
CONCENTRATIONS

Fig. 2 Schematic chart of principal wind-connected oceanic features of the Gulf of Tehuantepec during the season of northerly winds; heavy broken line indicates the prevailing surface current pattern, lighter broken line a variation of this pattern resulting in a pair of eddies; for further explanation, see text

order of 100 ml/1000 m^3 in May and September, and 600 ml/1000 m^3 in November and January.

Towards the end of the Tehuantepecer season the pycnocline topography presumably flattens, upward movement of water diminishes, and production and standing crops of biota decline. Summer conditions in the Gulf are probably rather uniform, as suggested above, and oligotrophic.

These oceanic features and processes are indicated schematically in Fig. 2. Detailed charts and profiles of horizontal and vertical property distributions are available elsewhere (Blackburn 1962).

4 HYPOTHETICAL DISTRIBUTION OF TUNA IN THE GULF

The following considerations (a-d) were used to justify a preliminary hypothesis about gross temporal and spatial variations in distribution and abundance of yellowfin tuna in the Gulf of Tehuantepec and adjacent waters, for testing with data available from the records of the fishery.

(a) Alverson (MS) has shown that yellowfin eat a wide variety of species of small nekton and large zooplankton. The possibility that yellowfin aggregate when and where such food is plentiful merits consideration for the following reasons. They make extensive movements in parts of the eastern tropical Pacific; some of the movements appear to have some seasonal regularity, and these include movements between the Gulf of Tehuantepec and the northern limit of the fishery (Schaefer et al 1961); the moving fish would require food and have good opportunities of encountering concentrations of it. Yellowfin seem to be ready to feed under most circumstances, as suggested by the presence of food in 76 percent of the large and diverse collection of stomachs examined by Alverson (MS); in the Gulf of Tehuantepec and adjacent waters, food occurred in 84 percent of stomachs. Yellowfin can be attracted to food at close range, both visually (indicated by the way they snap at odorless prey-like lures in the daytime) and chemically (Tester et al 1952, 1954, 1955).

(b) If yellowfin aggregate as suggested upon concentrations of their prey, they might also aggregate upon concentrations of small zooplankton. Small zooplankton are not a major item of yellowfin food, but they probably constitute the diet (or part of it) of most species on which yellowfin do feed, and an association between small zooplankton and yellowfin prey could be expected. The idea was suggested by the fact that standing crops of small zooplankton and small nekton, measured at the same stations in the eastern tropical Pacific in April, May and June 1958, were significantly and positively correlated; however, this was not true of similar standing crops in January and February 1959 (Blackburn and associates 1962).

(c) There are indications of statistically significant positive relationships of the kinds suggested above, i.e. between abundance of tuna and abundance of organisms in its food web, in the eastern tropical Pacific (Blackburn and associates 1962). The evidence of the relationships is not strong, but it exists for the two periods in which both kinds of information are available in the same months in the greatest numbers of 1-degree rectangles: these are April, May, and June 1958 (period of Cruise TO-58-1 of the Scripps Institution of Oceanography), and January and February 1959 (period of Cruise TO-59-1). The following measurements, of abundance of animals in or near the tuna food web, were made on the cruises; standing crops of small zooplankton, total small nekton, and four components of the small nekton (fish; cephalopods; large crustaceans; and a remainder equivalent to large zooplankton), all in displacement volume per standard volume of water strained. Attempts were made to correlate these six measurements with the commercial baitboat catch per standardized fishing day of yellowfin (both periods) and yellowfin plus skipjack (period of Cruise TO-58-1 only), in the same 1-degree rectangles and months; skipjack were caught in only a few of the rectangles in which food web organisms were sampled on Cruise TO-58-1, and in none of the rectangles so sampled on Cruise TO-49-1. Two of the 18 correlation coefficients were significant at the 5 percent level of probability, both positive in sign: yellowfin plus skipjack (mostly yellowfin) with large crustacea on TO-58-1, and yellowfin with small zooplankton on TO-59-1. The numbers of degrees of freedom in the tests ranged from 18 to 31.

(d) It was shown in section 3 that the highest concentrations of small zooplankton all occurred in a particular area. If these observations have been validly interpreted as effects of oceanic phenomena regularly resulting from Tehuantepecers, similar distributions of small zooplankton should occur over most of the Tehuantepecer season (October through April); and occasionally in May and September at a lower level of abundance; and perhaps occasionally in June, July and August, although a uniform distribution of sparse zooplankton throughout the Gulf is more to be expected at that season. The area in which the highest concentrations of small zooplankton are expected is between 13° and 150° N latitude and 94° and 97°W longitude: this includes all previously observed locations of such concentrations and parts of the pycnocline topography thought to be associated with them (Blackburn 1962).

It was therefore hypothesized that yellowfin tuna are characteristically distributed in the Gulf of Tehuantepec in the way that small zooplankton are: most abundantly in the Tehuantepecer season from October through April, and then in the area between 13° and 15°N, 94° and 97°W; least abundantly, and uniformly over the region, in the calm season from June through August; and in an intermediate way in May and September.

This hypothesis was seen to have possible weaknesses, especially in the argument from a few observed zooplankton distributions to a general one (d above) and thence to a similar contemporaneous distribution of tuna prey (b above). It was the best one that could logically be advanced for testing, however, and it was thought that testing might lead to its improvement. It is tested in section 5 and discussed in section 6.

Little information exists to justify the application of this or any similar hypothesis to skipjack tuna. A cursory examination of fishery records showed that the distribution of skipjack is very different from that of yellowfin, and that the above-mentioned hypothesis could not possibly apply to skipjack. The differences between the distributions of the two species are shown and discussed in sections 5 and 6.

5 ACTUAL DISTRIBUTION AND ABUNDANCE OF TUNA IN THE GULF

5.1 Yellowfin

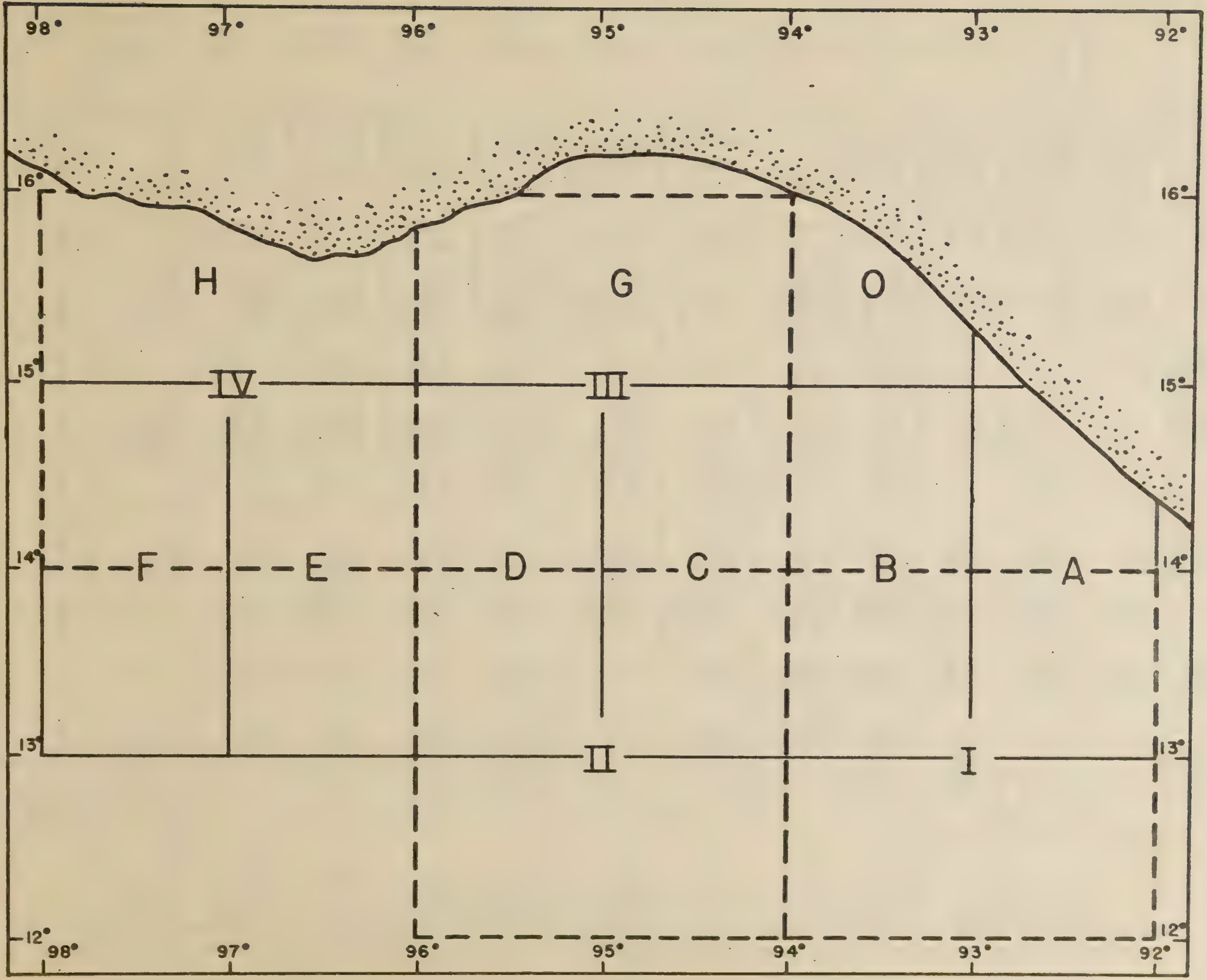
The Inter-American Tropical Tuna Commission collects data on catch in tons of each species of tuna and on numbers of fishing days, for the bait-boat and purse-seine fisheries separately, by 1-degree rectangles and months. The Commission and the United States Bureau of Commercial Fisheries co-operate in preparing tabulations of catch, numbers of days, and mean catch per standardized fishing day. The catch per standardized fishing day, explained by Shimada and Schaefer (1956), is considered to be the best available measurement of average apparent abundance of yellowfin or skipjack. The data analyzed in this paper, for both yellowfin and skipjack, were taken from an unpublished tabulation supplied by the Bureau in December 1961: they were checked as far as possible with the original records of the Commission, and the discrepancies noted were all trivial for the purpose of this paper. Only bait-boat fishery records were used: the purse-seine fishery in the Gulf of Tehuantepec was small until about 1959.

Fig. 3 shows the 1-degree rectangles in the region, which were grouped for the purpose of this paper into eight 2-degree rectangles A, B, ...H. Rectangles C, D, and E are those in which tuna would be expected to be most abundant during the Tehuantepecer season, according to the hypothesis developed above. The odd 1-degree rectangle is designated 0; it is an area on the continental shelf in which few tuna of either species are caught.

Table I shows the total catch and number of fishing days for yellowfin over the period March 1951, through February 1960, dissected by months and areas (O, A, B, ...H). The catch and day entries were obtained by adding those for the 1-degree rectangles. Similar information for the earlier part of 1951 and the later part of 1960 was not used: in the former period the data-gathering system, which began in January 1951, was probably less efficient than it became later; in the latter period the bait-boat fishery was small in size.

Table I also shows the mean catch per day for each month for the combined areas. This index is highest in March, April, and May, a period which is broadly identifiable with the later part of the Tehuantepecer season; so for further grouping of the data of Table I it is convenient to use the four quarter-years March-May, June-August, etc. Table II presents the data of Table I in that way, with catch per day for each period and area; it also gives catch, days, and catch per day for each area for the whole year.

The period December-February is broadly identifiable with the peak of Tehuantepecer activity, which declines in the period March-May;


98°
97°
96°
95°
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16°
15°
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13°
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H
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D
C
B
A
II
I

Fig. 3 Gulf of Tehuantepec and adjacent waters, showing areas A-H (2° x 1°), and area 0 (1° x 1°) referred to in Tables I to XI, and areas I to IV (2° x 2°) referred to in Figs. 4 and 5

Table I

Yellowfin in the Tehuantepec baitboat fishery, March 1951-February 1960; number of tons caught (T), and number of standardized fishing days (D), by areas shown in Fig. 3, and by months; tons per day (T/D) shown for combined areas in each month.

Measurement	Area	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
T D	0	1.5 7.0	17.7 24.7	13.2 20.6	18.0 26.3	42.5 25.8	26.0 12.7	1.0 5.5	4.0 2.6	5.0 2.8	3.9 7.5	0.0 4.1	1.1 5.0
T D	A	590.3 88.0	401.7 133.8	485.0 167.8	576.2 142.6	326.0 111.2	164.3 65.0	407.6 130.9	93.2 47.1	67.7 26.1	58.0 48.8	33.7 19.1	165.1 42.3
T D	B	384.0 68.8	858.1 184.9	307.6 123.5	1215.0 197.4	822.6 182.4	660.7 156.8	71.1 38.1	53.9 27.2	140.6 47.3	185.8 72.1	355.5 57.8	18.1 14.7
T D	C	8.4 5.4	67.4 27.0	463.4 75.8	767.3 107.3	1714.9 207.3	46.7 25.8	2.5 4.2	4.8 7.8	23.5 6.4	8.0 5.3	2.0 5.1	69.6 9.8
T D	D	12.2 4.5	618.1 54.7	1339.8 141.2	1412.2 104.8	780.8 126.6	21.2 13.4	2.5 1.5	1.5 4.7	2.0 1.0	2.0 2.0	3.0 2.8	0.0 0.6
T D	E	77.4 29.5	1162.0 130.3	1092.5 169.9	1484.3 194.8	209.2 65.4	16.2 10.7	15.5 6.1	0.9 4.3	1.5 1.0	20.5 9.4	27.0 6.8	65.5 7.6
T D	F	271.4 64.5	426.3 105.7	149.0 56.0	1422.7 220.2	167.6 50.3	70.5 11.9	0.0 0.5	2.0 2.2	2.0 1.2	2.5 4.1	9.2 7.4	228.7 22.0
T D	G	40.9 30.7	131.0 73.0	435.5 123.5	395.9 137.4	1437.7 224.6	131.0 52.5	87.7 27.8	30.6 31.1	59.2 20.7	5.0 12.7	26.4 21.5	11.7 15.5
T D	H	337.8 118.2	257.7 157.3	1597.5 320.8	535.5 177.0	950.8 230.2	103.8 60.4	162.7 42.3	44.0 26.0	53.9 21.8	102.0 30.6	18.1 24.2	76.7 33.6
T D T/D	Total	1723.9 416.6 4.14	3940.0 891.4 4.42	5883.5 1199.1 4.91	7827.1 1307.8 5.98	6451.5 1223.8 5.27	1240.4 409.2 3.03	750.6 256.9 2.92	234.9 153.0 1.54	355.4 128.3 2.77	387.7 192.5 2.01	474.9 148.8 3.19	636.5 151.1 4.21

Table II

Data of Table I (yellowfin) grouped by three-month periods

Measurement	Area	Dec-Feb.	Mar.-May	June-Aug.	Sept.-Nov.	Total
T	O	20.3	73.7	31.0	8.9	133.9
D		36.7	72.7	20.8	14.4	144.6
T/D		0.55	1.01	1.49	0.62	0.93
T	A	1157.1	1387.2	665.1	159.4	3368.8
D		264.1	421.6	243.0	94.0	1022.7
T/D		4.38	3.29	2.74	1.70	3.29
T	B	1260.2	2344.6	785.7	681.9	5072.4
D		268.4	503.3	222.1	177.2	1171.0
T/D		4.70	4.66	3.54	3.85	4.33
T	C	145.4	2945.6	54.0	33.5	3178.5
D		42.2	390.4	37.8	16.8	487.2
T/D		3.45	7.55	1.43	1.99	6.52
T	D	630.3	3532.8	25.2	7.0	4195.3
D		59.8	372.6	19.6	5.8	457.8
T/D		10.54	9.48	1.29	1.21	9.16
T	E	1304.9	2786.0	32.6	49.0	4172.5
D		167.4	430.1	21.1	17.2	635.8
T/D		7.80	6.48	1.55	2.85	6.56
T	F	926.4	1739.3	72.5	13.7	2751.9
D		192.2	326.5	14.6	12.7	546.0
T/D		4.82	5.33	4.97	1.08	5.04
T	G	183.6	2269.1	249.3	90.6	2792.6
D		119.2	485.5	111.4	54.9	771.0
T/D		1.54	4.67	2.24	1.65	3.62
T	H	672.2	3083.8	310.5	174.0	4240.5
D		309.1	728.0	128.7	76.6	1242.4
T/D		2.17	4.24	2.41	2.27	3.41
T	Total	6300.4	20162.1	2225.9	1218.0	29906.4
D		1459.1	3730.7	819.1	469.6	6478.5
T/D		4.32	5.40	2.72	2.59	4.62

the period September-November includes the beginning of the activity. It might therefore be expected that catch per day would be highest in December-February and lowest in June-August. In fact the maximum for the combined areas occurs in March-May and the minimum in September-November (Table II). Catch per day is highest for the year in December-February or March-May for all areas except 0; it is lowest for the year in one of the other two periods for all areas except G, H, and O. These remarks apply particularly to areas C, D, and E, where catch per day shows the greatest seasonal range (>6 tons in three-monthly means); the smallest seasonal range (<1 ton) occurs in area 0. Areas C, D, and E have also the highest catch per day for all seasons combined, and 0 has the lowest. Means for different areas have a greater range in December-February (>9 tons; highest in D and E, lowest in 0) than in any other quarter-year, the smallest range occurring in September-November (<4 tons; highest in B, lowest in 0). These results agree fairly well with the hypothesis as far as the suggested best areas for yellowfin are concerned, but the suggested best and worst seasons for yellowfin seem to occur about three months later than expected; this is discussed below.

A more rigorous examination of the data was attempted by analysis of variance of catch per day means by areas, seasons, and years. It was decided, from experience in handling the data, that no mean should be based on<5 days and that the base should be>10 days whenever possible; as a result the data prior to March 1953 were excluded, those subsequent to February 1957 were with difficulty included, and only two seasons were recognized (March-May, with 58 percent of all fishing days; and the rest of the year). Area 0 was ignored. The means were multiplied by 100, raised by 1.00 and logged. Table III gives the data used in the analyses of variance; each entry for the period June-February is assigned to the earlier of the two calendar years in which the period falls.

Table IV gives the results of three analyses, (i), (ii) and (iii), made in the manner of Snedecor (1946, p. 304 et seq.): area, season, and year are considered as fixed effects and second order interaction is taken as the estimate of experimental error. Analysis (i) is for the five years 1953 to 1957 with the abovementioned eight areas and two seasons; three of the 80 catch per day means were based on <10>5 days. Analyses (ii) and (iii) represent different attempts to utilize the data of 1958 and 1959, when fishing effort was much lower than in the previous years, without introducing too many low-based means; special interest attaches to these years because most of the oceanographic work was done then. In (ii), 1958 and 1959 were regarded as a single year (making six), with eight areas and two seasons as before; six of the 96 means were based on <10>5 days. In (iii), 1958 and 1959 were considered separately (giving a total of seven years), but four areas of low fishing effort (C, D, E, F) were regarded as a single area (hence five areas in all): two seasons were recognized as before; one of the 70 means was based on<10 = 5 (actually 4.9) days.

It was expected from Tables II and III that the season effect would be significant: it was included in the analyses mainly to obtain enough degrees of freedom to test the first-order interactions, none of which are significant. Actually the season effect, although large, is not significant in analysis (iii); it is significant in (i) and (ii). The year effect is not significant at all. The area effect is almost significant in analysis (iii), where F for areas = 4.16 (cf. F= 4.22 for significance at P = 0.05); it is fairly large although not significant in (i) and (ii) and the same is true of the area-season interactions.

In view of these observations and the hypothesis under consideration, it was decided to analyze the data of (i) and (ii) further for the separate seasons; i.e., with areas and years as main effects (Snedecor 1946, p.253 et seq.). The results are given in Table V: neither effect is significant in June-February; the area effect is highly significant in March-May although the year effect is not significant. For the combined years the highest logged means in the March-May analyses are for areas D, C and E, in that order. It is shown by the D test (Snedecor 1956, p. 251-253) that the mean for area D differs significantly from those of areas A, F, G, and possibly H; the mean for area C differs significantly from those of areas A and G, however the mean for area E is not significantly different from any other: this statement applies to both (i) and (iii) in Table V. In the data of Table IV (iii), the combined areas C, D, E and F have a higher logged mean in March-May than the means for the individual areas A, B, G and H, although none of the differences is quite significant.

Table III

Yellowfin in the Tehuantepec baitboat fishery, March 1953-February 1960; number of tons caught (T), number of standardized fishing days (D), and log ((100. T/D) + 1), by areas, years and seasons

Measurement	Area	1953		1954		1955		1956		1957		1958		1959		1958 + 1959	
		Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.
T	A	45.9	9.5	44.6	668.6	407.4	111.0	146.0	493.5	525.6	49.4	26.0	75.5	162.5	39.7	188.5	115.2
D		28.8	28.0	43.9	113.9	75.1	45.1	60.5	129.4	127.3	39.0	20.5	33.3	38.0	22.6	58.5	55.9
log		2.2041	1.5441	2.0128	2.7694	2.7348	2.3927	2.3838	2.5821	2.6170	2.1072	2.1072	2.3579	2.6325	2.2480	2.5092	2.3160
T	B	246.0	48.4	130.1	439.3	852.8	145.9	74.9	1031.6	507.4	202.2	23.7	375.4	87.5	351.4	111.2	726.8
D		66.1	38.6	51.1	116.2	111.1	30.2	37.5	246.7	111.0	51.5	16.2	62.6	36.1	51.2	52.3	113.8
log		2.5717	2.1004	2.4082	2.5786	2.8859	2.6848	2.3032	2.6222	2.6609	2.5955	2.1673	2.7789	2.3856	2.8370	2.3304	2.8062
T	C	221.4	100.8	692.2	4.7	580.8	6.5	320.5	53.0	839.8	34.0	40.5	21.0	78.4	0.0	118.9	21.0
D		37.3	20.5	89.5	11.0	64.5	10.0	28.9	25.2	104.0	14.1	14.2	4.7	21.0	1.0	35.2	5.7
log		2.7745	2.6928	2.8887	1.6435	2.9547	1.8195	3.0453	2.3243	2.9070	2.3838	2.4564	2.6513	2.5729	0.0000	2.5302	2.5670
T	D	1081.2	7.5	456.8	26.7	405.1	523.1	1198.1	12.2	296.7	6.0	0.0	78.5	73.4	7.0	73.4	85.5
D		86.7	6.7	68.9	10.5	29.0	44.5	118.5	6.6	43.7	5.7	1.5	7.2	16.3	1.3	17.8	8.5
log		3.0962	2.0531	2.8222	2.4065	3.1456	3.0708	3.0051	2.2695	2.8325	2.0253	0.0000	3.0378	2.6542	2.7316	2.6160	3.0029
T	E	1138.6	48.2	228.1	54.2	201.1	1084.7	923.6	110.0	123.3	68.5	1.5	11.2	47.0	0.0	48.5	11.2
D		121.0	16.6	51.9	11.3	48.4	102.3	126.1	37.4	34.3	20.3	2.6	13.7	16.0	1.0	18.6	14.7
log		2.9741	2.4639	2.6435	2.6821	2.6191	3.0257	2.8651	2.4698	2.5563	2.5289	1.7709	1.9191	2.4698	0.0000	2.4183	1.8865
T	F	1186.1	138.9	155.1	150.7	95.5	206.8	52.9	322.0	29.9	183.6	2.0	9.4	9.5	0.5	11.5	9.9
D		141.8	29.6	52.7	24.9	24.0	40.4	33.0	71.7	13.1	38.0	2.2	10.9	4.4	1.6	6.6	12.5
log		2.9227	2.6721	2.4698	2.7825	2.6010	2.7101	2.2068	2.6532	2.3598	2.6848	1.9590	1.9395	2.3365	1.5051	2.2430	1.9031
T	G	60.7	106.5	331.1	54.5	136.6	4.70	218.0	143.9	63.6	70.1	159.2	72.4	178.0	55.0	337.2	127.4
D		38.5	37.1	89.4	37.8	39.9	24.3	53.8	59.3	44.3	44.2	35.5	21.9	34.1	23.9	69.6	45.8
log		2.2014	2.4594	2.5694	2.1614	2.5353	1.3010	2.6085	2.3874	2.1614	2.2041	2.6522	2.5211	2.7185	2.3636	2.6857	2.4456
T	H	357.0	13.0	816.8	232.8	190.3	182.7	1268.2	304.0	94.2	95.9	12.0	65.7	123.6	77.5	135.6	143.2
D		99.8	54.3	158.9	57.3	66.6	68.2	214.2	119.5	48.1	75.8	26.8	37.4	37.4	36.3	64.2	73.7
log		2.5551	1.3979	2.7118	2.6090	2.4579	2.4298	2.7731	2.4065	2.2945	2.1072	1.6628	2.2480	2.5198	2.3304	2.3263	2.2900
T	C,D,E,F,	3627.3	295.4	1532.2	236.3	1282.5	1821.1	2495.1	497.2	1289.7	292.1	44.0	120.1	208.3	7.5	252.3	127.6
D		386.8	73.4	263.0	57.7	165.9	197.2	306.5	140.9	195.1	78.1	20.5	36.5	57.7	4.9	78.2	41.4
log		2.9727	2.6053	2.7664	2.6138	2.8887	2.9657	2.9112	2.5490	2.8209	2.5740	2.3345	2.5185	2.5587	2.1875	2.5105	2.4900

Table IV

Analyses of variance of logs in Table III according to areas, years and seasons

Analysis	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
(i)	Areas	7	1.7931	0.2562
	Years	4	0.3371	0.0843
	Seasons	1	1.3883	1.3883 *
	Areas X Years	28	2.6132	0.0933
	Areas X Seasons	7	1.6660	0.2380
	Years X Seasons	4	0.3390	0.0848
	Areas X Years X Seasons	28	7.8155	0.2791
(ii)	Areas	7	1.5433	0.2205
	Years	5	0.4063	0.0813
	Seasons	1	1.2560	1.2560 **
	Areas X Years	35	3.6934	0.1055
	Areas X Seasons	7	1.2023	0.1718
	Years X Seasons	5	0.4835	0.0967
	Areas X Years X Seasons	35	3.6520	0.1043
(iii)	Areas	4	1.3065	0.3266 +
	Years	6	0.7193	0.1199
	Seasons	1	0.3037	0.3037
	Areas X Years	24	2.2427	0.0934
	Areas X Seasons	4	0.3367	0.0842
	Years X Seasons	6	0.9697	0.1616
	Areas X Years X Seasons	24	1.8834	0.0785

(i), with areas A,B,C,D,E,F,G,H, and years 1953-1957

(ii), with same areas, and same years plus (1958 + 1959)

(iii), with areas A,B,G,H and (C + D + E + F), and years 1953-1959

*significant at P = 0.05, **significant at P = 0.01,

+ almost significant at P = 0.05

Table V

Analyses of variance of logs in Table III according to areas and years

Analysis	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
(i)	Areas	7	1.7019	0.2431 **
	Years	4	0.1965	0.0491
	Error	28	1.2698	0.0454
(ii)	Areas	7	1.7572	0.2510
	Years	4	0.4797	0.1199
	Error	28	4.1342	0.1476
(iii)	Areas	7	1.5353	0.2193 **
	Years	5	0.4034	0.0807
	Error	35	1.5735	0.0450
(iv)	Areas	7	1.2104	0.1729
	Years	5	0.4865	0.0973
	Error	35	5.7691	0.1648

(i) as for (i) in Table IV, March-May only

(ii) " " (i) " " IV, June-February only

(iii) " " (ii) " " IV, March-May only

(iv) " " (ii) " " IV, June-February only

* significant at P = 0.05, ** significant at P = 0.01

Table VI

Yellowfin in the Tehuantepec baitboat fishery in the period December-February; number of tons caught (T), number of standardized fishing days (D) and log ((100 T/D) + 1) by areas and years

Measurement	Area	1953	1954	1955	1956	1957	1958	1959	1958 + 1959
T	A	3.5	464.4	75.1	417.4	15.2	75.5	8.5	84.0
D		12.2	47.8	29.4	80.9	15.0	29.8	10.5	40.3
log		1.4771	2.9881	2.4082	2.7135	2.0086	2.4048	1.9138	2.3201
T	B	8.4	28.0	72.0	772.7	44.1	290.9	18.2	309.1
D		17.4	9.3	9.3	141.9	16.6	46.4	9.4	55.8
log		1.6902	2.4800	2.8893	2.7372	2.4265	2.7980	2.2900	2.7443
T	C	93.8	0.0	6.5	18.4	0.0	18.0	0.0	18.0
D		15.3	1.5	5.7	11.2	1.8	3.0	0.5	3.5
log		2.7882	0.0000	2.0607	2.2175	0.0000	2.7789	0.0000	2.7118
T	D	0.5	13.0	520.6	10.2	0.5	78.5	7.0	85.5
D		3.5	3.0	41.7	2.9	1.2	6.2	1.3	7.5
log		1.1761	2.6375	3.0965	2.5478	1.6335	3.1028	2.7316	3.0573
T	E	24.2	51.5	1084.7	80.0	54.5	10.0	0.0	10.0
D		12.8	7.1	98.4	23.0	15.2	10.9	0.0	10.9
log		2.2788	2.8609	3.0425	2.5428	2.5563	1.9685	0.0000	1.9685
T	F	138.9	150.7	202.8	317.5	112.1	3.4	0.5	3.9
D		27.5	23.4	36.2	66.4	27.8	8.5	1.6	10.1
log		2.7042	2.8096	2.7490	2.6803	2.6064	1.6128	1.5051	1.6021
T	G	65.5	7.0	0.0	39.5	26.9	9.5	29.0	38.5
D		18.0	6.1	10.9	23.7	15.1	9.6	11.3	20.9
log		2.5623	2.0645	0.0000	2.2253	2.2529	2.0000	2.4116	2.2672
T	H	12.0	77.1	168.2	265.4	42.5	41.5	47.5	89.0
D		29.5	23.0	55.6	86.0	37.4	30.6	22.2	52.8
log		1.6232	2.5263	2.4829	2.4914	2.0607	2.1367	2.3324	2.2304
T	C,D,E	118.5	64.5	1611.8	108.6	55.0	106.5	7.0	113.5
D		31.6	11.6	145.8	37.1	18.2	20.1	1.8	21.9
log		2.5752	2.7459	3.0437	2.4683	2.4814	2.7251	2.5911	2.7152

These results agree with the hypothesis in showing that yellowfin are consistently and significantly more plentiful in area C and D, especially D, than in other areas to the east, north and west, in the latter part of the Tehuantepecer season. It is not shown, however, that this applies to area E.

From the original hypothesis a similar result would be expected for the period December-February, but it cannot be demonstrated. Table VI lists the logged means of catch per day for this period for the different years and areas; several of these means have low bases because fishing effort is lower in December-February than in March-May. Table VII gives the results of an analysis of variance on 36 means which were chosen so that only five of them were based <10 >5 days. Neither the area nor the year effect is significant.

It is noteworthy that no significant year effect or area-year interaction appears in any analysis of yellowfin data.

5.2 Skipjack

Tables VIII and IX present catch and catch per day data for skipjack in the way that Tables I and II do for yellowfin: numbers of days are the same for both species and therefore not repeated in Tables VIII and IX. The mean catch per day of skipjack for all areas and seasons is 0.87 tons (Table IX); the corresponding figure for yellowfin is 4.62 tons (Table II). The seasonal and spatial distribution is quite different in the two species: for instance, skipjack catch per day in the combined areas is higher in September-November than in any other quarter-year, and for the combined seasons it is higher in B and A than in any other areas.

For further study by analysis of variance the 1953-1959 data are assembled in Table X, corresponding to Table III for yellowfin. This brings out the fact that skipjack were absent from most areas after February 1957, and absent from all areas except B after February 1958. It was therefore appropriate to confine the analysis to the four years 1953 to 1956, with eight areas and two seasons as for yellowfin in Table IV (i) (ii); two of the 64 means were based on <10 >5 days. Table XI gives the results: only the year effect is significant. The season effect is practically unmeasurable for these data, but Table IX strongly suggests that a different result would have been obtained if 1951 and 1952 data had been included, or if a different grouping of quarter-years had been made; these things were not done, as explained in connection with the yellowfin analyses, because they would have introduced many more low-based means. It is probably safe to conclude that skipjack are more abundant in the half-year June-November than in December-May, which is the opposite of the situation for yellowfin. Nothing can be said with confidence about differences between areas but differences between years are manifest; in these respects again the distribution of skipjack differs markedly from that of yellowfin. The hypothesis developed above obviously is not true for skipjack.

A D test of differences between year means showed that catch per day was not significantly different between 1954, 1955, and 1956, whereas it was significantly higher in each of those years than it was in 1953. In 1957, 1958, and 1959, the catch per day was virtually nil, as mentioned above.

6 DISCUSSION

It has been shown that the original hypothesis about distribution and abundance of tuna by season and area, derived from oceanography with the aid of certain assumptions as explained in section 4, is partly supported by the most trustworthy yellowfin data. It is not at all supported by skipjack data. The hypothesis did not deal with possible changes from year to year: in the outcome such effects appear to be negligible for yellowfin and very important for skipjack.

Specifically, the yellowfin data agree with the preliminary hypothesis in that areas C and D, which normally cover the southern part of the pycnocline ridge and waters immediately west of it, have a significantly higher catch per day than other areas further east, north, and (in the case of area D) west, in the last two or three months of the Tehuantepecer season. They disagree with the hypothesis in that (i) they show no similar difference for the peak of the Tehuantepecer season, or (ii) for area E at any time, and (iii) that changes in catch per day for the whole region occur about three months later than the supposedly related changes in the weather and ocean cycle. Of these three points of disagreement, (ii) is the least serious; it could merely mean that the highest concen-

Table VII

Analysis of variance of logs in Table VI for areas A, B, F, G, H and (C + D + E), and years 1953-1958

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Areas	5	2.5542	0.5108
Years	5	1.0753	0.2151
Error	25	7.4917	0.2997

Table VIII

Skipjack in the Tehuantepec baitboat fishery, March 1951-February 1960; number of tons caught (T) by areas and months; see Table I for number of standardized fishing days (D): tons per day (T/D) shown for combined areas in each month

Measurement	Area	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
T	0	0.0	0.0	0.0	8.0	0.0	0.7	20.8	2.0	3.0	50.8	0.0	0.0
T	A	10.2	2.6	47.3	60.7	58.8	104.5	431.6	82.1	35.0	258.2	1.2	58.7
T	B	1.0	49.9	6.5	66.9	99.9	519.4	60.9	42.6	280.3	643.8	47.5	0.0
T	C	0.0	3.5	38.8	108.7	108.3	5.0	1.0	30.9	56.0	21.0	5.0	3.3
T	D	0.0	84.0	162.7	89.2	45.0	1.5	2.0	0.0	0.0	0.0	3.0	0.0
T	E	4.8	198.0	140.0	73.0	6.5	0.0	4.0	0.0	0.0	65.0	0.0	62.5
T	F	17.1	67.7	2.5	120.6	3.5	0.0	0.0	0.0	0.0	22.0	2.0	254.8
T	G	0.0	0.0	40.4	27.9	20.8	16.2	0.0	108.3	60.5	14.0	0.0	0.0
T	H	23.0	28.4	181.1	92.0	30.0	0.0	2.2	21.5	26.4	50.0	0.0	15.0
T	Total	56.1	434.1	619.3	647.0	372.8	647.3	522.5	287.4	461.2	1124.8	58.7	394.3
T/D		0.13	0.49	0.52	0.49	0.30	1.58	2.03	1.88	3.59	5.84	0.39	2.61

Table IX

Data of Table VIII (skipjack) grouped by three-month periods; see Table II for number of standardized fishing days (D)

Measurement	Area	Dec.-Feb.	Mar.-May	June-Aug.	Sept.-Nov.	Total
T	0	0.0	8.0	23.5	53.8	85.3
T/D		0.00	0.11	1.13	3.74	0.59
T	A	71.5	166.8	618.2	294.4	1150.9
T/D		0.27	0.40	2.54	3.13	1.13
T	B	50.9	173.3	622.8	971.6	1818.6
T/D		0.19	0.34	2.80	5.48	1.55
T	C	6.8	255.8	36.9	82.0	381.5
T/D		0.16	0.66	0.98	4.88	0.78
T	D	84.0	296.9	3.5	3.0	387.4
T/D		1.40	0.80	0.18	0.52	0.85
T	E	265.3	219.5	4.0	65.0	553.8
T/D		1.58	0.51	0.19	3.78	0.87
T	F	339.6	126.6	0.0	24.0	490.2
T/D		1.77	0.39	0.00	1.89	0.90
T	G	0.0	89.0	124.5	74.5	288.0
T/D		0.00	0.18	1.12	1.36	0.37
T	H	66.4	303.2	23.8	76.4	469.8
T/D		0.21	0.42	0.18	1.00	0.38
T	Total	884.5	1639.1	1457.2	1644.7	5625.5
T/D		0.61	0.44	1.78	3.50	0.87

Table X

Skipjack in the Tehuantepec baitboat fishery, March 1953-February 1960; number of tons caught (T) and log ((100. T/D) + 1) by areas, years and seasons; see Table III for number of standardized fishing days (D)

Measurement	Area	1953		1954		1955		1956		1957		1958		1959	
		Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.	Mar.-May	June-Feb.
T	A	4.0	3.0	11.9	162.6	56.5	106.3	39.4	205.7	55.0	1.0	0.0	0.0	0.0	0.0
log		1.1761	1.0792	1.4472	2.1584	1.8808	2.3747	1.8195	2.2041	1.6435	0.6021	0.0000	0.0000	0.0000	0.0000
T	B	6.7	3.0	64.9	485.8	52.0	38.8	23.4	936.8	6.3	12.2	0.0	5.2	0.0	4.0
log		1.0414	0.9542	2.1072	2.6222	1.6812	2.1106	1.7993	2.5809	0.8451	1.3979	0.0000	0.9542	0.0000	0.9542
T	C	26.0	5.3	108.3	0.5	84.7	2.0	36.8	110.9	0.0	0.0	0.0	0.0	0.0	0.0
log		1.8513	1.4314	2.0864	0.7782	2.1206	1.3222	2.1072	2.6444	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
T	D	3.0	3.5	46.0	1.5	85.2	85.5	162.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
log		0.6021	1.7243	1.8325	1.1761	2.4698	2.2856	2.1399	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
T	E	59.1	0.0	9.1	10.0	14.4	191.8	136.9	129.0	0.0	0.0	0.0	0.0	0.0	0.0
log		1.6990	0.0000	1.2788	1.9494	1.4914	2.2765	2.0414	2.5391	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
T	F	41.2	59.8	75.0	0.0	4.4	53.9	5.5	248.9	0.0	1.0	0.0	0.0	0.0	0.0
log		1.4771	2.3075	2.1553	0.0000	1.2788	2.1271	1.2553	2.5416	0.0000	0.6021	0.0000	0.0000	0.0000	0.0000
T	G	2.0	0.0	20.8	38.1	3.2	1.2	63.0	155.7	0.0	0.0	0.0	0.0	0.0	0.0
log		0.7782	0.0000	1.3802	2.0086	0.9542	0.7782	2.0719	2.4216	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
T	H	72.4	3.0	34.0	77.5	14.3	15.0	182.5	69.3	0.0	0.0	0.0	0.0	0.0	0.0
log		1.8692	0.8451	1.3424	2.1335	1.3424	1.3617	1.9345	1.7709	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

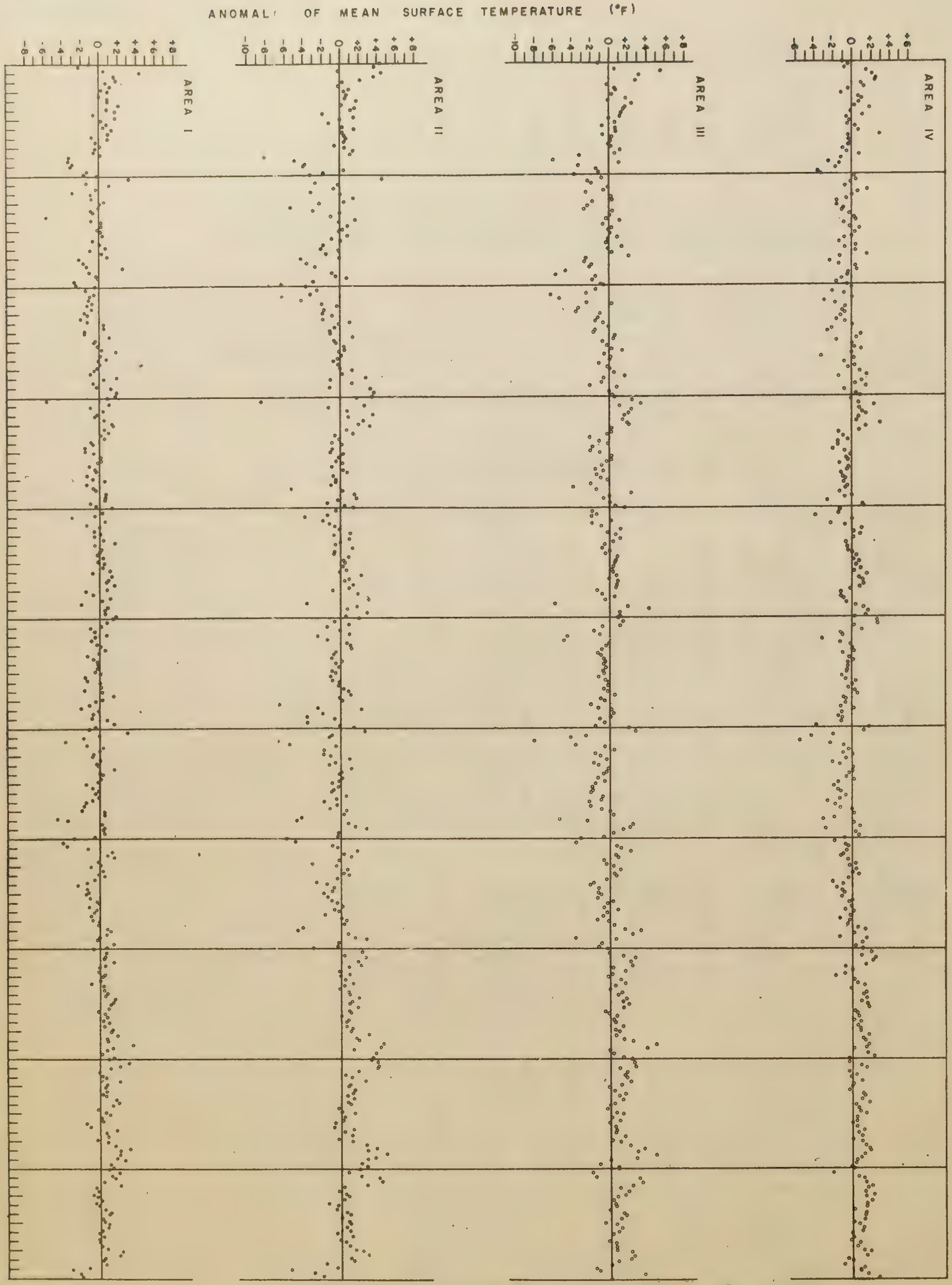

Fig. 4 Anomalies of 10-day means of surface temperature (°F), from means for corresponding periods based on all 1949-1959 data, in areas I-IV of Fig. 3

trations of biota do not regularly extend into area E, although they did so on some of the past cruises. The other two points of disagreement, (i) and (iii), would disappear if it could be shown that the annual cycle of abundance of tuna prey lags about three months behind the annual cycle of weather and associated ocean conditions described above. This cannot be shown, but it is not an unreasonable assumption since yellowfin feed mainly on small nekton, which might well have an average age of the order of three months; it amounts to a virtual denial of the unsupported point (b) in section 4.

The hypothesis may therefore be modified accordingly, until it can be further tested. It still says that yellowfin are distributed according to the distribution of their food in space and time, and this distribution can be understood in some detail by reference to a series of oceanic phenomena connected with the annual weather cycle; but it now assumes a lag of about three months between changes at the physical, chemical, and lower biological levels on the one hand, and changes at the higher biological levels on the other.

There is no evidence of difference in distribution and abundance of yellowfin at any one season over the seven-year period 1953-1959. Admittedly the fishing effort was smaller in 1958 and 1959 than in the previous years, and this necessitated a grouping of data for analysis which might have obscured a small difference in catch per day between those two years, or between them and the other years; but it may confidently be said that there was no large difference over the whole period.

This is of considerable interest because there were marked differences in the only other property of the Gulf waters for which data exist over the same period, namely surface temperature. Fig. 4 shows for each of four areas that surface temperatures were average in 1953, low in 1954 and 1955, low or average in 1956, high in 1957 and 1958, and high or average in 1959; similar variations occurred in the four previous years (high in 1949, low in 1950, average in 1951 and 1952); the variable in Fig. 4 is the anomaly for a given 10-day period based on the 1949-1959 average for the period. The reasons for this series of changes are not understood, although its likeness to contemporaneous series in other parts of the eastern Pacific has been pointed out (Blackburn and associates 1962). No consistent differences are observable between winter (Tehuantepecer season) and summer anomalies of surface temperature in the same year. Similar records of wind velocity (unspecified as to direction, but considered as northerly in the winter months) show no obvious departure from the long-term average for a given time of year in any of the years (Fig. 5). It may be concluded that the annual cycle of local weather is regular; that this circumstance (referring to the observations and argument above) imposes a regularity upon the annual cycle of distribution and abundance of yellowfin; and that this regularity in the yellowfin cycle is normally undisturbed by the longer-period oceanic changes that affect surface temperatures in the Gulf and other parts of the eastern Pacific from time to time.

The areas (I-IV) referred to in Figs. 4 and 5 were chosen to give the longest possible series of adequately-based 10 day means (see Roden 1961 for previous work on some of these data). The original data were provided by the United States Weather Bureau. The areas are shown in Fig. 3.

There are several points of correspondence between the major changes in surface temperature anomaly with time in these areas (Fig. 4) and the above-mentioned time changes in skipjack catch per day. Catch per day was lower in 1953 (temperature generally average in areas I-IV) than it was in 1954-1956 (temperature generally lower than average in areas I-IV, except in area III where it was average in 1956), and then declined very greatly in 1957-1959 (temperature generally higher than average in areas I-IV, except in areas I and II where it was average in 1959). The change from low to high temperature occurred about the beginning of 1957, and the change in skipjack catch per day occurred at about the same time (Table X). The temperature increased least in area I; this includes part of area B, the only area in which some skipjack remained through 1957 to 1959 (Table X).

It is therefore probable that there is an inverse relation between surface temperature (actual temperature or anomaly) and skipjack abundance over a certain range of the former, with skipjack abundance falling to zero above a certain temperature (or anomaly) in a way that suggests exclusion of the fish by the temperature. Detailed investigation of this relationship would

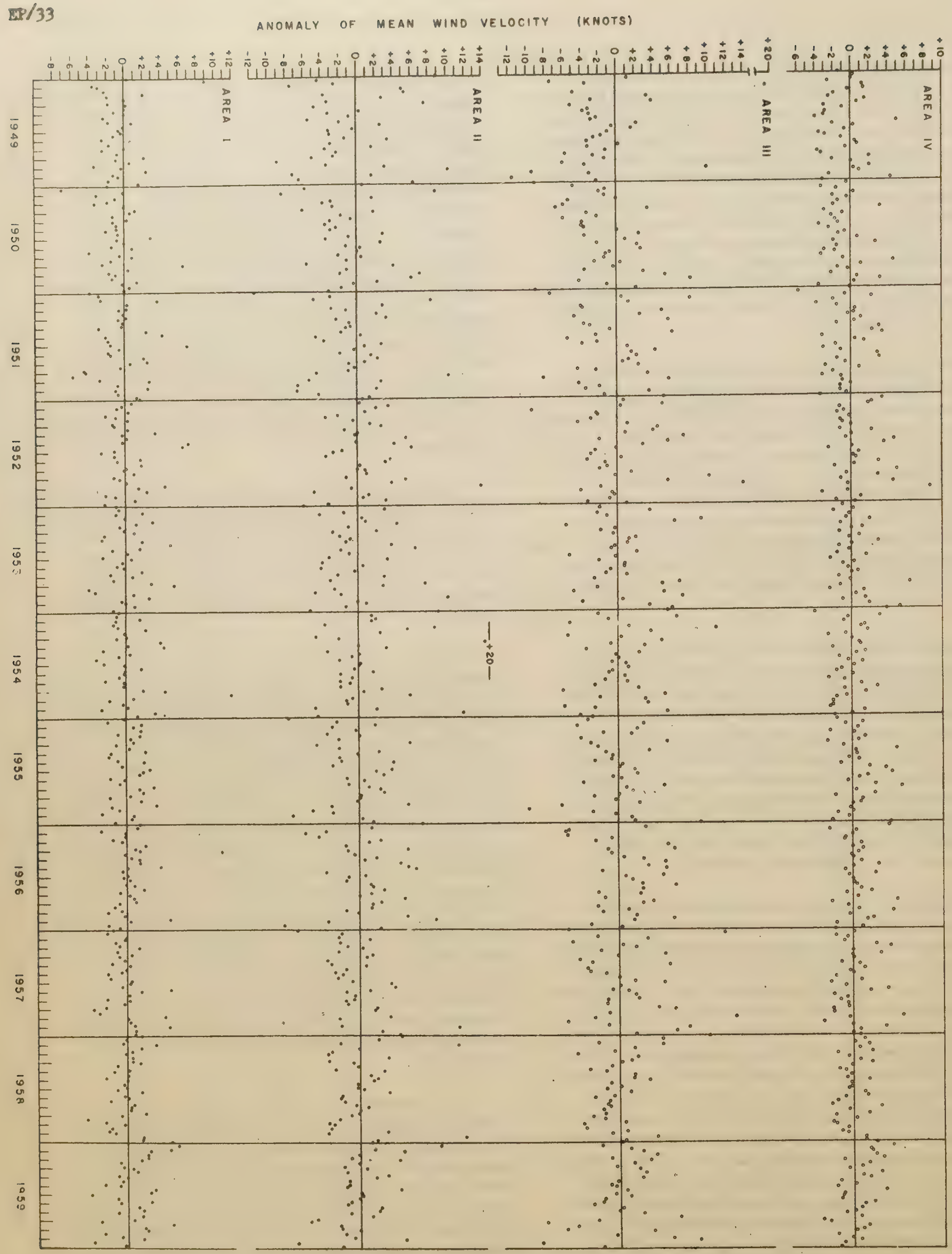

Fig. 5 Anomalies of 10-day means of wind velocity (knots), from means for corresponding periods based on all 1949-1959 data, in Areas I-IV of Fig. 3

Table XI

Analysis of variance of logs in Table X according to years (1953-1956 only), areas and seasons

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Areas	7	1.7768	0.2538
Years	3	5.5744	1.8581*
Seasons	1	0.0000	0.0000
Areas X Years	21	8.6245	0.4107
Areas X Seasons	7	1.6485	0.2355
Years X Seasons	3	0.6025	0.2008
Areas X Years X Seasons	21	10.6776	0.5084

* significant at P = 0.05, ** significant at P = 0.01

require the temperature and skipjack data to be reassembled into a single set of areas and periods, which has not yet been done. Such investigations may throw some light on the distribution of skipjack by areas and seasons as well as years.

As shown above, it is unlikely that any similarly close relationship exists between surface temperature and yellowfin; Table III shows that yellowfin did not disappear in the warm years as the skipjack did, and there is no evidence of any change in their abundance in those years.

It was shown that the area effect is significant and the year effect not significant for yellowfin catch per day in the period March-May (section 5.1, Table V), despite marked differences in surface temperature between several of the years; the area effect was that catch per day in areas C and D was higher than in several other areas and not surpassed in any. It is therefore probable that fishermen could obtain a higher catch of yellowfin per day in areas C and D than in other areas at the period March-May, which is the height of the yellowfin fishing season. Their own past experience shows this kind of distribution in the years 1953 to 1959, and the explanation through oceanography provides reasonable assurance that the distribution will recur in any year in which weather and ocean conditions fall within the range observed in 1953 to 1959. Tables I to III show that lower baitboat fishing effort is expended in areas C and D than in most other areas; this is partly because these areas are particularly exposed to northerlies, which might limit purse-seine fishing even more than baitboat fishing. The fishermen would probably find it more profitable to seek yellowfin in areas C and D than elsewhere in the Gulf region, whenever weather conditions offer them the choice, in the period March-May of any year. Of course the catch per day levels of 1953 to 1959 could not be expected if the yellowfin populations declined for reasons unaffected by the environment, e.g. by overfishing; but however abundant the fish are, they will tend to be more plentiful in areas C and D than in the other areas considered in this paper.

Experience Paper No. 34

STUDIES OF OCEANIC FRONTS IN THE MOUTH OF THE GULF OF CALIFORNIA, AN AREA OF TUNA MIGRATIONS

By

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Abstract

A review of the literature shows that it is widely believed that small biota (e.g. plankton, micronekton) and pelagic fish tend to be especially abundant at fronts, but few detailed studies of this have been made. The present paper shows the distribution of physical and biological oceanographic properties at certain fronts in a region through which tuna migrate.

Fronts in the mouth of the Gulf of California may be formed, in the upper 120 m, by two of three types of water: (i) Gulf of California; (ii) California Current; (iii) equatorial Pacific. The front best developed and studied is off Cape San Lucas, Lower California, in spring and summer; the cool, low-salinity, upwelled water contrasts well with the warm, saline Gulf water. Vertically, this front has a Z-shaped interface.

Biological property distributions show that certain kinds of biota were more numerous in the middle of this front than on either side, and may therefore have been accumulated by convergence at the front. Marlin were observed in the area at the time of the observations, but tuna were not. Commercial catch and effort data on yellowfin are available by one-degree rectangles and by months, but this scale is too gross to show any clear relation to the front.

ETUDES DES FRONTS OCEANIQUES A L'ENTREE DU GOLFE DE CALIFORNIE, ZONE DE MIGRATION DU THON

Résumé

L'examen de la bibliographie montre que l'abondance particulière sur les fronts océaniques de petits biota et de poissons pélagiques est une idée très largement répandue, mais qu'il y a peu d'études de détail à ce sujet. Cet article traite de la distribution des propriétés océanographiques, physiques et biologiques, sur certains fronts dans une zone où migrent les thons.

Les fronts à l'entrée du golfe de Californie peuvent être formés dans les 120 m supérieurs par deux de trois types d'eaux: (i) golfe de Californie, (ii) courant de Californie, (iii) Pacifique équatorial. Le front le plus développé et le mieux étudié

est au large du Cap San-Lucas, Basse Californie, au printemps et en été; l'eau de remontée, froide et de faible salinité, contraste nettement avec l'eau chaude et salée du golfe. Sur le plan vertical ce front présente une interface en forme de Z.

La distribution des propriétés biologiques montre que certains types de biota sont plus nombreux dans la partie médiane de ce front que sur les autres côtés et pourraient avoir été accumulés en conséquence par une convergence sur ce front. On a noté la présence de marlin dans cette zone au cours des observations, mais non celle du thon. On dispose de données sur le volume de capture et sur l'effort de pêche dans des rectangles d'un degré et par mois, mais cette échelle est trop large pour qu'on puisse déceler une relation nette avec le front.

ESTUDIOS DE LOS FRENTES OCEANICOS EN LA BOCA DEL GOLFO DE CALIFORNIA, ZONA DE EMIGRACIONES DEL ATUN

Extracto

Un examen de la literatura revela que está muy difundida la idea de que la biota pequeña y los peces pelágicos tienden a abundar especialmente en los frentes oceánicos, pero de ello se han hecho pocos estudios profundos. En esta ponencia se da a conocer la distribución de propiedades oceanográficas físicas y biológicas en ciertos frentes de una región por la que emigra el atún.

En la boca del Golfo de California pueden formar frente, en los 120 m. superiores, dos de tres clases de agua: (i) del Golfo de California; (ii) de la corriente de California; (iii) del Pacífico ecuatorial. El frente más claro y mejor estudiado es el del Cabo San Lucas, Baja California, en primavera y verano; el agua de surgencia fría y de baja salinidad contrasta con la cálida y salina del Golfo. Verticalmente este frente tiene una superficie en forma de Z.

La distribución de las propiedades biológicas demuestra que ciertas clases de biota son más numerosas en el centro que en los lados de este frente y es posible, por lo tanto, que se hayan acumulado por convergencia. Al hacerse las observaciones se vio pez aguja en la zona, pero no atunes. Se dispone de datos de captura industrial y de esfuerzos de pesca de atún de aleta amarilla en rectángulos de un grado y por meses, pero esta escala es demasiado grosera para mostrar una relación clara con el frente.

1 INTRODUCTION

The most prominent oceanographic features of the entrance to the Gulf of California, though they vary considerably in time, space, and intensity, are oceanic fronts, found usually near Cape San Lucas at the southern end of Lower (Baja) California and sometimes at Cape Corrientes (Fig. 1).

There is no precise definition in oceanography of the term "front", which has apparently been widely adopted from meteorologists. Cromwell and Reid (1956) say "A front will mean a band along the sea surface across which density changes abruptly". This definition has the advantage that it does not particularize the more readily measured properties (temperature and salinity) that determine the density change. As a rule, assuming that the front is not visible, it is best indicated by a thermograph. It is quite possible for the density change to be due entirely to salinity differences, however. This leads to the use of such terms as temperature fronts and salinity fronts.

Uda (1959) appears to take the view that a front (siome) is a boundary between two different kinds of water. He says, "Then the boundaries of the water mass are in the region where the gradients of the property are maximum (i.e. the Polar Fronts, etc.)".

La Fond (1961) uses the following definition: "The leading edge of a border separating unlike water masses is called a front. Fronts can occur not only between water masses of different salinity but also between those differing in other properties, such as temperature".

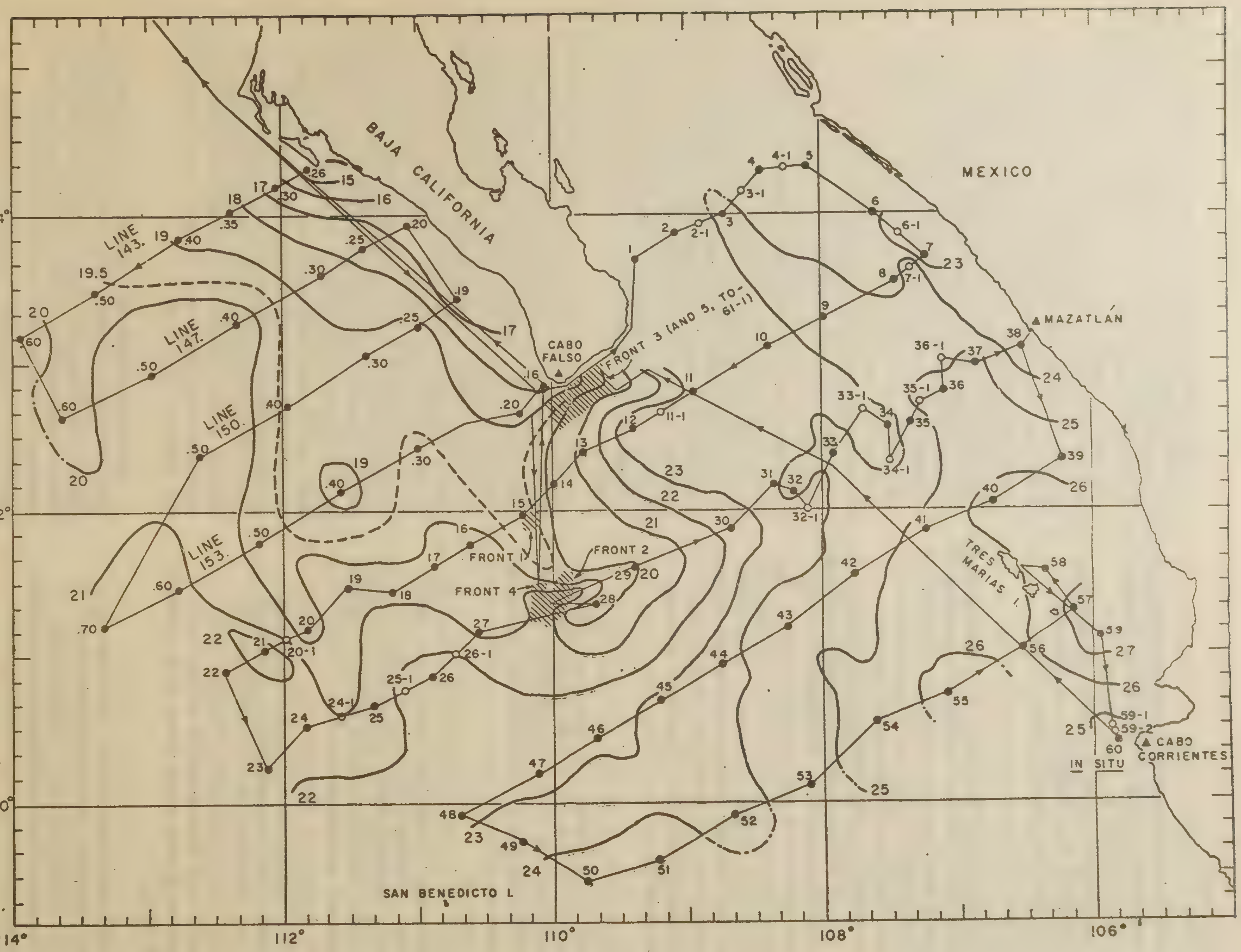
The term "water mass" in these definitions is used loosely, not necessarily in conformity with Sverdrup, Johnson, and Fleming (1942). For example, fronts are often found between upwelled water and non-upwelled water, both kinds pertaining to one water mass in the sense of Sverdrup et al.

Uda (1959) specifies a front, in terms of a temperature gradient, as varying from 0.5°C/10 miles to 5.0°C/10 miles. This tenfold difference between limits illustrates the inevitable lack of precision in any definition of an oceanic front.

The best known fronts (perhaps better called frontal systems, using the word front for sections of those systems that we investigate) are those between the cool, low-salinity polar waters and the warm, more saline, subtropical waters: the Arctic and Antarctic Convergences; and those between the Equatorial Counter-current and the North and South Equatorial Currents. Lesser known but important fronts occur between the Baltic outflow and the North Sea; between the outflow from the Gulf of California and the California Current and/or equatorial Pacific waters; and in regions of upwelling. These few examples cover a wide range of dimension and motion, and cannot be freely compared amongst themselves; they represent only a small selection of all known frontal areas (see Uda 1938). The zone of mixing between the Kuroshio and the Oyashio (and between the Gulf Stream and the Labrador Current) is so vast in certain times and places that some workers refer to the front between Kuroshio and mixed water as the Kuroshio front, and to that between the Oyashio and the mixed water as the Oyashio front; a similar distinction may be made in the western Atlantic where the mixed water is called Shelf water.

Important contributions to the knowledge of the front between the Kuroshio and the Oyashio have been made by Beklemishev and Burkov (1958); Burkov and Arseniev (1958); Fukuoka (1955); Hanzawa (1952); Kawai (1955); Masuzawa (1955a, 1955b); Siomina (1958); Uda (1938, 1943, 1953, 1954, 1955, 1958, 1959, 1961); Uda and Ishino (1958); and others. Important work on the Gulf Stream front has been done by Ford and Miller (1952); Fuglister (1951); Fuglister and Worthington (1951); Iselin and Fuglister (1948); Spilhaus (1940); Von Arx, Bumpus and Richardson (1955); and many others. The equatorial frontal systems have been studied by Austin (1960); Cromwell (1953, 1958); Cromwell and Reid (1956); King and Hida (1957); and others. Wyrtki (1960a, 1960b) and Mackintosh (1946) have contributed significantly to the understanding of the Antarctic polar front.

Although fronts are common off the coast of California and Lower California (as off any coast where upwelling is strong), study of them has been casual and incidental to the quasi-synoptic surveys of the whole region made by the California Co-operative Oceanic Fisheries Investigations (Cal. C.O.F.I.).


MEXICO
BAJA CALIFORNIA
▲MAZATLÁN
CABO FALSO
▲CABO CORRIENTES
TRES MARIAS I.
SAN BENEDICTO I.
FRONT 1
FRONT 2
FRONT 3 (AND 5, TO-61-1)
FRONT 4
LINE 143.
LINE 147.
LINE 150.
LINE 153.
IN SITU
24°
22°
20°
114°
112°
110°
108°
106°
1
2
2-1
3
3-1
4
4-1
5
6
6-1
7
7-1
8
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10
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11-1
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58
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59-1
59-2
60
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.35
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.70
19.5
26
30

Fig. 1 A map showing the track of the S.T.O.R. cruise TO-60-1 (stations 1 to 60) and part of the track of Cal. C.O.F.I. cruise 6004B (stations 143.26 - 153.16). Stippled areas show where fronts were studied on TO-60-1 and TO-61-1. Surface isotherms (°C) have been superimposed.

The view that convergent fronts aggregate plankton is apparently rather widely held. Uda (1938) describes the accumulation of flotsam at siome, or fronts, and Uda and Ishino (1958) indicate that convergent fronts show a line of biological demarcation owing to aggregation of biota. They go on to show the relationship of fisheries for albacore (Germo germo), skipjack (Katsuwonus pelamis) and bluefin (Thunnus orientalis) to the front between the cool Oyashio and the warm Kuroshio. La Fond (1961) continuing his definition, started above, says, "These fronts raise water of higher nutrient content to the surface. In addition, the fronts tend to concentrate floating fish food in adjacent areas". This raises the question of whether a front manifests a higher standing crop of plankton than does water on either side by aggregating the biota or by causing conditions specially favorable to the growth of a higher standing crop. This, in turn, probably depends on whether the front is convergent, in which case aggregation might be expected, or divergent, in which case nutrient-rich water might be brought to the surface to increase plankton growth. Uda (1959) suggests that the latter occurs at siome (p. 18 op. cit.) although those he discusses are apparently of the convergent type. Evidently, there is some conflict of possibilities. Siomina (1958) states that phytoplankton "blooms" are a feature of the area of mixing between the Kuroshio and Oyashio; whether these "blooms" are the result of in situ production or of mechanical aggregation is not stated. Perhaps both causes are responsible, with the in situ production being the more important.

King and Hida (1957) show, on a relatively large scale, a relation between high standing crop of zooplankton and the frontal system in the central equatorial Pacific, without, however, establishing the actual cause of the high plankton values. Indeed, the peak values are slightly south of the three fronts (parts of the system) they studied. Their results also show a somewhat lower quantity of plankton in the convergence zone (2° - 4°N) than in the divergence zone (2°S - 2°N). Beklemishev and Burkov (1958) show, from data obtained by the R/V Vitiaz, that plankton is more abundant in the zone of contact between the Oyashio and the Kuroshio than to either side, and that this plankton comprises forms from both biotopes (cool, low-salinity and warm, high-salinity). The zone of mixing is about four hundred miles wide, however, in the area studied. These authors further say: "The quantity of species in the zone of mingling of water masses sometimes turns out to be greater than each separately (Siomina 1957)". [1]

Some relatively precise results, kindly lent me by Mr. T. S. Austin of the United States Fish and Wildlife Service, show catches of zooplankton hauls within five to ten miles of a front in the equatorial central Pacific. The highest catches were in the front and on the warm side (about five miles away); the volumes fell off beyond that but were roughly the same five miles away on the cool side and ten miles away on the warm side. Again, these data do not indicate the cause of the plankton distribution. Knauss (1957), writing of a front apparently between South Equatorial Current water and Equatorial Counter-current water, says, "High biological activity was associated with the front; however, there was no floating debris. The cold water was relatively sterile; most of the life appeared to be concentrated in the relatively narrow frontal zone". These biological observations were made only by dipnet.

There is a definite relation between fish abundance and fronts, according to Uda (1953, 1954, 1959 and 1961). Japanese fisheries for bluefin, albacore and skipjack are closely related to the front between the Oyashio and the Kuroshio (Uda and Ishino 1958). The local Japanese whale fishery is also related to this large frontal system (Uda 1938, 1954). The front between the Gulf Stream and the Labrador Current is not the focus of intense fishing such as there is off Japan, perhaps because fisheries are well developed on the larger continental shelf in the western Atlantic. Nevertheless, tuna are strongly associated with the Gulf Stream front (Walford 1958; Rivas 1955).

Eggvin (1940) discusses the advance of a cold front of Baltic water through the Skagerrak, northwards along the Norwegian coast in the early spring; this is an example of a negative relationship, however, for the cold, low-salinity water drives spawning herring (Clupea harengus) offshore and out of their usually favored habitats; this phenomenon varies from year to year, causing annual fluctuations in the recruitment. Robins (1952) shows a marked increase in troll catches of skipjack tuna in a front (a relatively weak one) in the entrance to Storm Bay, Tasmania.

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[1] These authors do not give a publication by Siomina for 1957 in their literature citations, but do give one by him for 1958, which seems to be appropriate to their statement. This is included in the literature cited for the present paper.

Although fronts have commanded the interest of oceanographers in general, relatively little detailed work has been done on them (disregarding the large-scale studies of the major frontal systems), especially from a biological point of view. The investigations already mentioned are overwhelmingly physical and dynamical. Quantitative biological measurements in relation to fronts, especially of the smaller, sharper kind, are scant in the literature.

The fronts studied by Scripps Tuna Oceanography Research group (S.T.O.R.) are described below. They have two points of general interest: i) they have, judging from the literature, been more completely studied than any others (though not necessarily in any particular detail); ii) they occur in an area that yellowfin (Neothunnus macropterus) and possibly skipjack tuna normally migrate across at a time of year when the fronts are best developed. Hence, these studies contribute to our knowledge of a relatively ill-known phenomenon; and the fronts may have an influence on the seasonal movement of tuna into the "local banks" fishery off the west coast of Lower California, though we do not know this yet.

A manuscript describing in detail the fronts studied by the S.T.O.R. group is being prepared for publication in the Special Scientific Report - Fisheries Series of the United States Department of the Interior, Fish and Wildlife Service. Many figures and data from that manuscript that cannot be presented in this paper are drawn upon freely here for the purpose of discussion.

2 OCEANOGRAPHIC CRUISES

S.T.O.R. cruise TO-60-1 (30 April - 27 May, 1960) was made to study the physical, chemical and biological properties of the entrance to the Gulf of California at a time when, normally, yellowfin and possibly skipjack tuna are migrating from the west coast of the Mexican mainland across or into the Gulf of California and thence to the west coast of Lower California (Alverson 1960; Griffiths 1960; Inter-American Tropical Tuna Commission Annual Reports, 1960 and 1961). Complementing this survey was a study of oceanic fronts known to be common there (Reid, Roden and Wyllie 1958; Roden and Groves 1959).

Using the experience gained in the observation of the four fronts studied on TO-60-1, further study was made of one of them (at Cape San Lucas) at the end of S.T.O.R. cruise TO-61-1 (19 - 24 April, 1961). The results obtained from this latter study form the body of this paper.

Apart from the S.T.O.R. cruises to the mouth of the Gulf, there are a number of Cal. C.O.F.I. cruises which went either into the Gulf or down to Cape San Lucas; these have been used to gain an idea of the variation in time and space of the Cape San Lucas front. These cruises, numbered by year and month, with Scripps Data Report references, are: 5011 (51-47), 5109 (51-38), 5401 (58-38), 5412 (60-1), 5501 (59-36), 5502 (59-36), 5503 (59-37) 5512 (60-4), 5601 (60-5), 5602 (60-5), 5604 (60-6), 5612 (61-22), 5702 (58-22), 5704 (58-24), 5706 (58-33), 5708 (58-63), 5801 (59-3), 5908 (61-19), 6001 (61-23), and 6004 (62-6). Data from the Vermilion Sea Expedition, 13 April to 29 May, 1959 (60-51), were also used.

3 RESULTS

3.1 The General Area

Fig. 1 shows the track of cruise TO-60-1 and part of Cal. C.O.F.I. cruise 6004 (MV Black Douglas), which ended at Cape Falso (about 3 mi west of Cape San Lucas) on 30 April 1960. The surface isotherms and areas in which fronts (1, 2, 3, 4 and 5) were studied are superimposed. The striking features are: i) the frontal system formed by the 20°, 21°, 22° and 23°C isotherms, extending from the southern tip of Lower (Baja) California roughly southwards for about 100 mi then turning westwards, eventually becoming weaker; fronts were found within this system ii) the strong indication of upwelling inshore along the west coast of Lower California, with apparent southward transport of the upwelled water; iii) the intrusion of warm water (24°, 25°, and 26°C isotherms) into the Gulf along its eastern side. This distribution of surface temperatures agrees qualitatively with those drawn from the data of Cal. C.O.F.I cruises 5604 and 5704 (both in April, like TO-60-1) and from the Vermilion Sea Expedition (April to May 1959). The configuration of the isotherms at the surface, on TO-60-1, persisted more or less to a depth of about 50 m, but became modified below that depth. Most of the data of TO-60-1 have been processed and drawn, and form the basis for some of the present discussion. For economy of space such drawings have not been figured.

The isohalines agree qualitatively with the isotherms, confirming that the frontal system is formed from warm, saline water to the east and cool, less saline water to the west and northwest; the salinity contours also persist to at least 50 m deep. Horizontal contours of most of the other properties substantiate this picture. Even so, vertical profiles, especially of salinity, between stations 7 and 22, and 23 and 38, show that the area is a very complicated one in the upper 100 m.

Our investigation of fronts has been, then, the study of very small sections of a rather large frontal system; it is an assumption that what was found applies more or less to the whole system. Moreover, the sections studied have shown much more intense gradients than appear in Fig. 1, but this is certainly a function of the density of observations in time and space.

3.2 The Fronts

Quite the best front, from the standpoint of oceanographic study, is that immediately offshore from Cape San Lucas (fronts 3 and 5, Fig. 1). This is because the land protects the sea surface from the prevailing northwest winds which would, and do out to sea, mix the surface waters. (Thermocline depth is much greater out to sea than in the mouth of the Gulf). The mixing has, for instance, made it rather hard to decide confidently what kinds of water formed fronts 2 and 4. Front 1, judging from the temperature regime (Fig. 1), was between upwelled water and non-upwelled water in the California Current system.

Fig. 2 shows the distribution of surface isotherms as derived from the initial thermograph survey (19 to 20 April, 1961) of front 5. The high node ($T > 23^{\circ}C$) to the north and east, and the intrusion of cool water ($T < 20^{\circ}C$) from the west, are the chief features; the front is formed between the warm and the cool waters. This fundamental plan was still present five days later when a final thermograph survey (23 to 24 April) was made (Fig. 3); the warm water had, however, moved westwards inshore, while the cool water had moved eastwards offshore, the front being maintained between them (Fig. 3). Other fronts out to sea (1, 2 and 4) were much faster moving and less stable, and therefore harder to study.

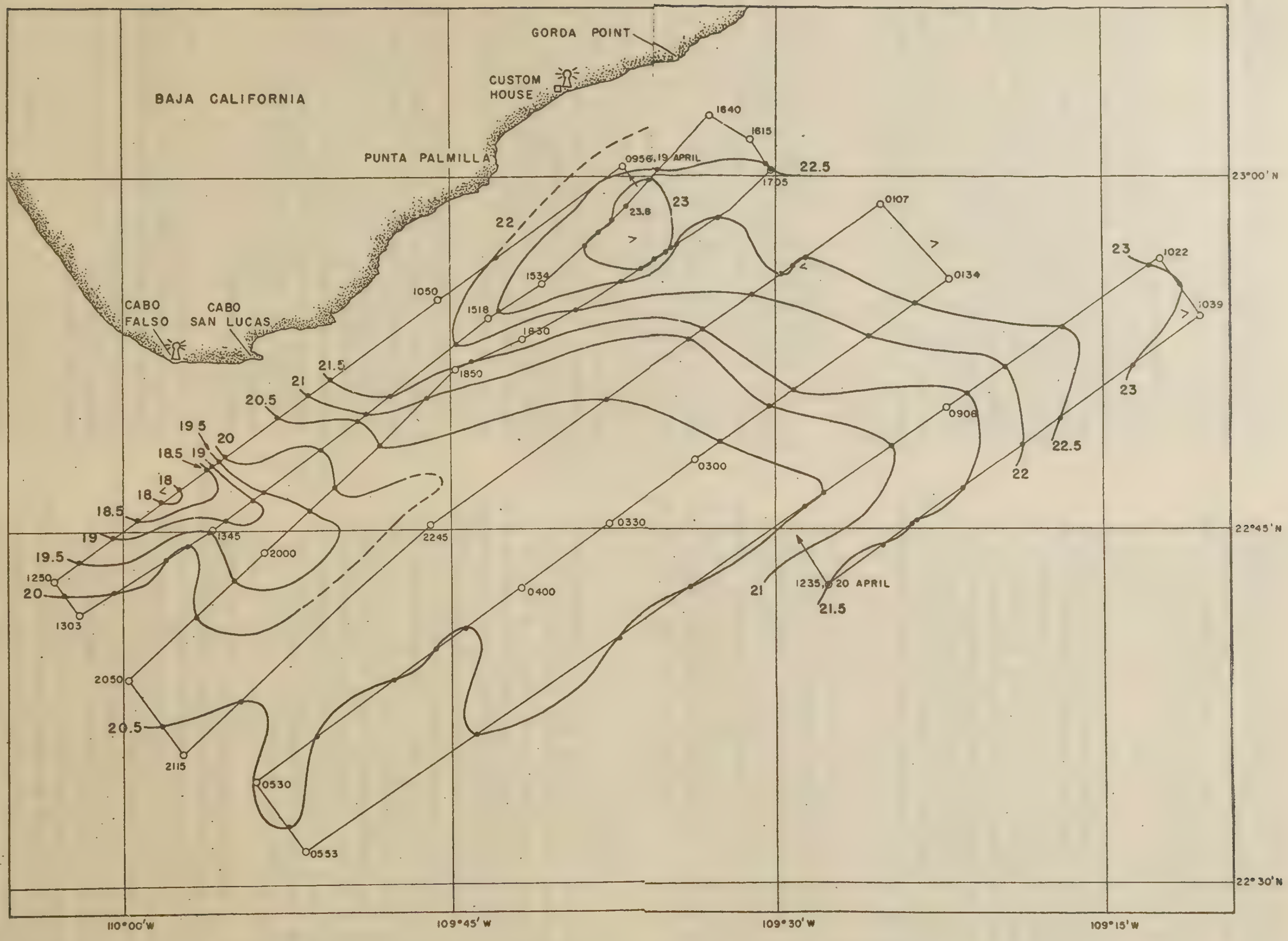
Perhaps more gratifying than the stability of this front was its fundamental similarity to front 3 which was in the same area eleven months earlier (22 May, 1960). Fig. 4 shows the surface isotherms of front 3; the warm water west of the node ($T > 25^{\circ}C$) appears to have moved westwards cutting across cool water coming from the north and separating a parcel of it to form an eddy south of the front roughly opposite the warm node. Such a situation could arise from that found at front 5, which makes us think that fronts 3 and 5 are basically alike. Unfortunately, circumstances did not allow us to study front 3 further.

The westward movement of warm water at front 5 was shown by four drogues, two with parachute at 5 m depth and two with them at 50 m. These were put into the water near the middle or slightly towards the warm side of the front on the afternoon of 21 April, about 12 mi southeast of Punta Palmilla. All were observed till lost: two, one of each kind, for about 39 hours, two for about 51 hours. The southernmost one (nearest the cool water) moved first a little northwest, then southeast, and finally north, before being lost. The other three all moved first north, then roughly west, in warm water. These drogue movements are clear evidence of the westward movement of warm water inshore.

A G.E.K (Geomagnetic ElectroKinetograph) survey was made at the northeastern part of front 5 where it bends from an east-west line to a north-south one (see Figs. 2 and 3), about 10 mi southeast of Punta Palmilla. This survey showed that warm (surface) water was moving roughly southwest at 10-30 cm/sec. Two observations (no. 4 and 9 in Table I), in the bend in the front, showed that cool water was moving slowly eastwards.

The indication by the G.E.K. of water moving out of the mouth of the Gulf is in full accord with the view of Roden and Groves (1959) that surface water generally leaves the Gulf on its western side. They state that maximum transport is at about 50 m depth.

Having established the orientation and movement of the front, we then investigated it at depth. Three BT (BathyThermograph) passes


BAJA CALIFORNIA
GORDA POINT
CUSTOM HOUSE
PUNTA PALMILLA
CABO FALSO
CABO SAN LUCAS
23°00'N
22°45'N
22°30'N
110°00'W
109°45'W
109°30'W
109°15'W
0956, 19 APRIL
1235, 20 APRIL
1840
1815
1705
0107
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1022
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1534
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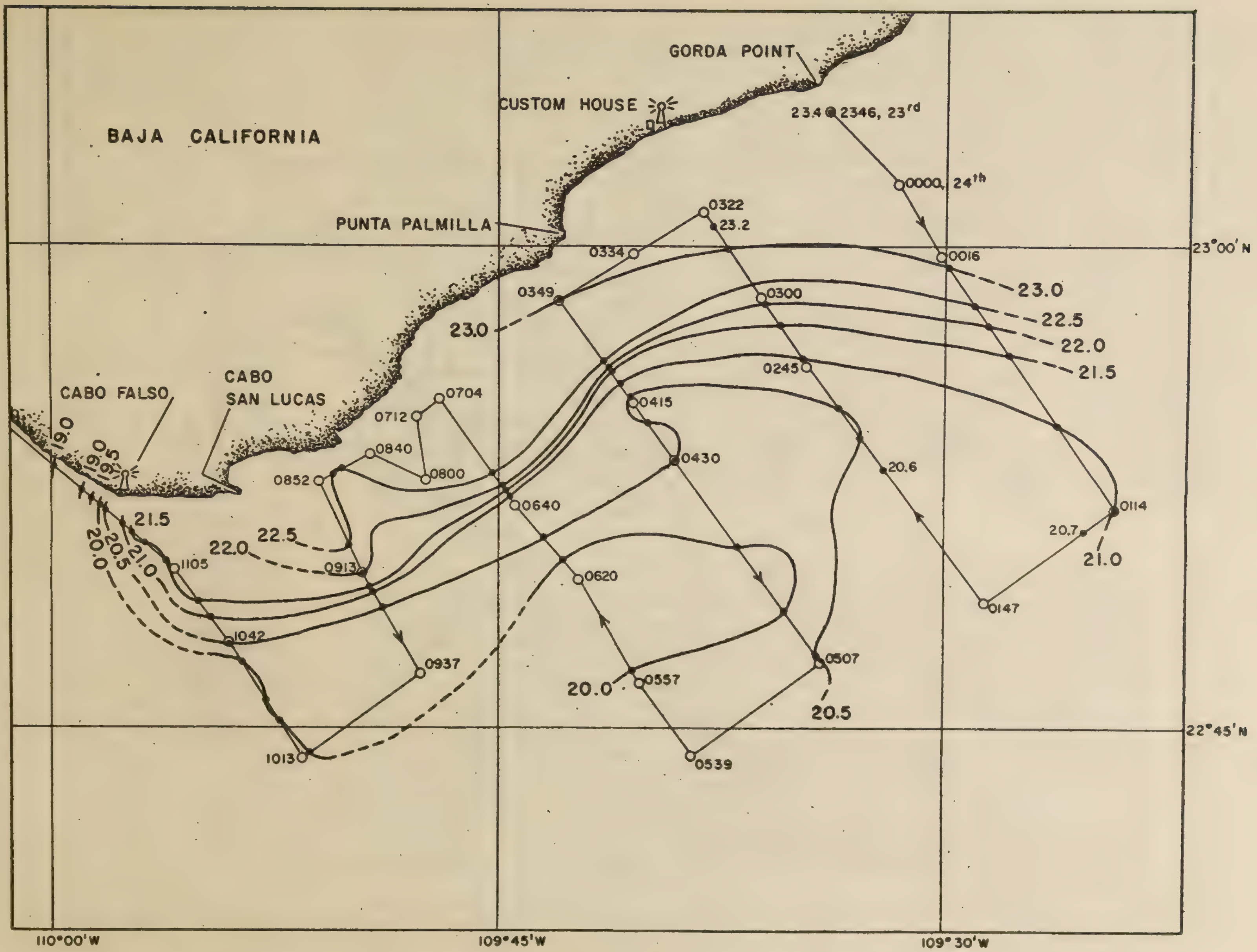
18

Fig. 2 Distribution of surface isotherms ($^{\circ}C$) at front 5, off Cape San Lucas, Lower California, from the initial thermograph survey (0956 hrs 19 April to 12,35 hrs 20 April 1961), the track of which is shown.
--o-- time check; --●-- temperature check.


BAJA CALIFORNIA
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23°00'N
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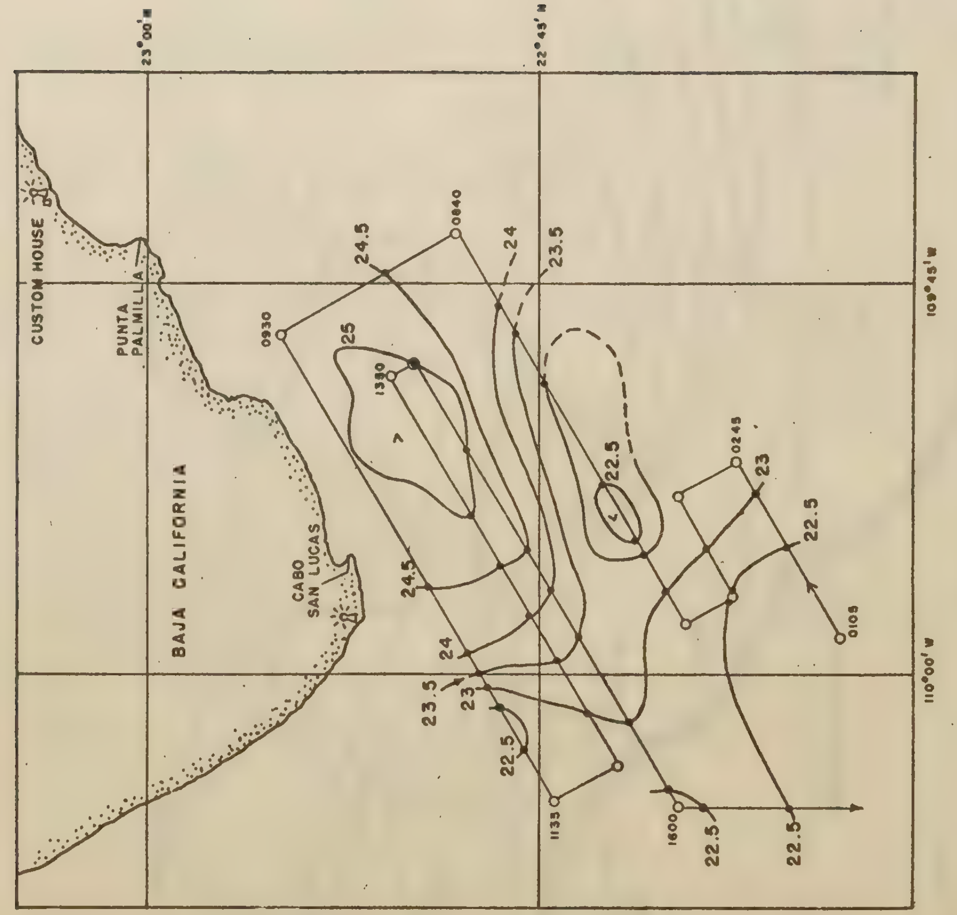
22.0
21.5
21.0
20.5
20.0
19.5
19.0

Fig. 3 Distribution of surface isotherms (^{o}C) at front 5, off Cape San Lucas, Lower California, from the final thermograph survey (2346 hrs 23 April to 1105 hrs 24 April 1961), the track of which is shown.
--o-- time check; --●-- temperature check.


23°00'N
22°45'N
109°45'W
110°00'W
CUSTOM HOUSE
PUNTA PALMILLA
BAJA CALIFORNIA
CABO SAN LUCAS
0840
0930
1330
0245
0105
1135
1600
24.5
24
23.5
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22.5
23
22.5
24.5
24
23.5
23
22.5
22.5
22.5

Fig. 4 Distribution of surface isotherms (°C) at front 3, off Cape San Lucas, Lower California, from a thermograph survey (0105 hrs - 1600 + hrs 22 May 1960), the track of which is shown.
--o-- time check; --●-- temperature check.

were made; a pass consisted of repeated rapid lowerings of a BT while the vessel moved slowly through the front. A bucket-thermometer reading of the surface temperature and a sample of water, for salinity determination, were taken with each BT. These passes were made about 12 mi southeast of Punta Palmilla.

Fig. 5 shows the temperature profile derived from one of the passes made at front 5. It does not differ qualitatively from those of the other two passes, but does encompass a somewhat greater range of surface temperature. The chief feature is the relatively complicated structure at depth compared with that at the surface. The warm water apparently intrudes into the cool, while the cool may intrude into the warm, complementarily (16°, 17°, 18° and 19°C isotherms). The 21°, 22° and 23°C isotherms, by which the front is detected by the thermograph, do not contribute to the large inversions at mid-depths (20 - 70 m).

A similar BT pass made at front 2 also showed a temperature structure at depth that was not revealed by observations at the surface. This deep (35 - 55 m) structure took the form of a layer of water of temperature about 20°C underlying surface water the temperature of which ranged from about 19.9°C to about 21.7°C across the front. This layer of water was interrupted in all three passes made there, being absent directly beneath the middle of the front as observed at the surface. This structure could be derived from that found at front 5, though this does not mean that the front 5 situation actually existed at front 2. Nevertheless, there is a strong indication that similar processes occur at both fronts, though presumably with different intensities.

Cromwell and Reid (1956) use the term "frontal layer" to mean the highly stratified boundary between the two kinds of water forming the front; in the fronts they reported, this layer was inclined towards the surface and became more or less horizontal at some depth above the main thermocline. Thus, the front observed on the thermograph corresponds to where the frontal layer meets the sea surface. Evidently, the Cape San Lucas frontal system has a more complicated, but perhaps less well-defined, frontal layer than those they observed. The 16°, 17° 18° and 19°C isotherms (Fig. 5) are not close together in the zone of inversion, which suggests that mixing occurs there. The stippled areas, following the presentation of Cromwell and Reid, show water that is practically isothermal vertically. In the fronts they reported on there was little salinity gradient, in which case density was almost entirely determined by temperature; hence vertical mixing would require least energy where water was vertically isothermal. This is much less true of fronts, such as the one being discussed, where salinity is important in determining density. There are five main parcels of water that are vertically isothermal: one is the surface water, another is the deep water (below the 14°C isotherm); the other three correspond to the intrusion of warm water and to the cool water above and below this warm intrusion. The main thermocline is at about 70 m depth on the cool side, and at between 30 m and 50 m depth on the warm side. There is a shallow thermocline on the cool side, formed by the 18°, 19° and 20°C isotherms which constitute the intrusion

Table I

No. of G.E.K. observation	1	2	3	4	5	6	7	8	9
Current direction (°True)	203	209	215	077	215	215	228	219	044
Current velocity (cm/sec)	11	19	3	16	11	30	22	26	4
Surface temperature at start of observation (°C)	22.5	22.0	21.0	20.2	22.0	22.8	22.3	21.3	21.0
1/	w	m	c	c	m	w	w	m	c

1/ For purposes of discussion, here and elsewhere, the surface temperature has been arbitrarily classified as warm (w) — > 22.0°C, middle (m) — 21.0° - 22.0°C, and cool (c) — < 21.0°C.

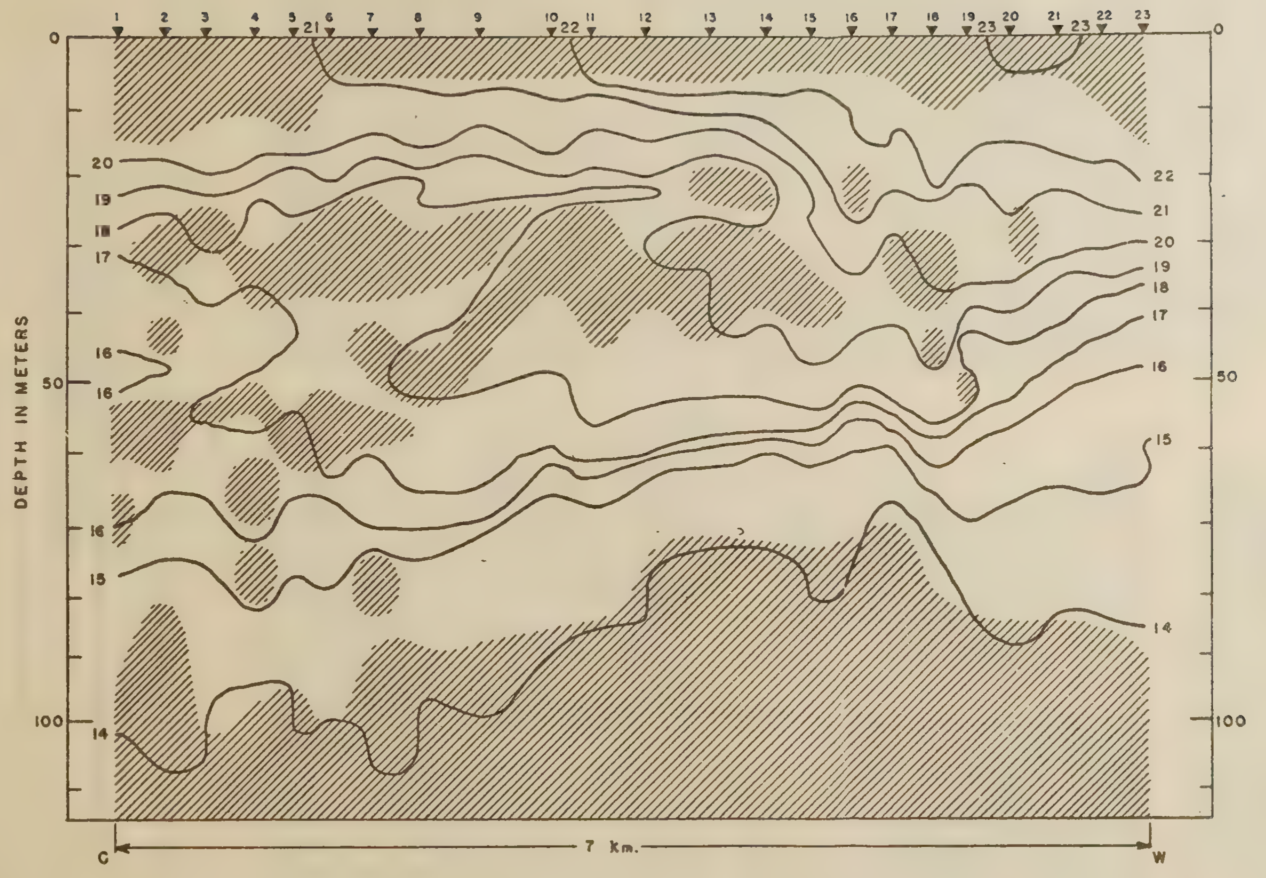

Fig. 5 The temperature profile ($^{\circ}C$) based on a BT pass (BT's Nos. 1 to 23) across front 5. Stippled areas indicate water that is practically vertically isothermal.
c - cool side; w - warm side.

of (probably) upwelled water from north of Cape Falso into the frontal area; these isotherms are shown in Fig. 2.

Fig. 6 shows the gradients of temperature (T), salinity (S), and thermosteric anomaly (δ_T) across front 5 at the surface; the temperature readings were from the bucket thermometers, and the salinity from the water samples collected with each BT on pass no. 3; δ_T was computed from these contemporaneous values of temperature and salinity. The close agreement of the temperature and salinity gradients shows that the front was formed by warm ($T \sim 23^{o}C$), saline ($S \gtrsim 35.00\,^{o}/oo$) water to the east and north, and by cool ($T \sim 20.5^{o}C$), less saline ($S \sim 34.60\,^{o}/oo$) water to the west and south. Comparable values for front 2 are: $19.6^{o}C$ - $34.32\,^{o}/oo$ and $21.6^{o}C$ - $34.72\,^{o}/oo$.

The temperature inversion at front 5, so obvious in Fig. 5 and the profiles based on the BT passes, appears in the temperature profile based on data from a triplet of 10-bottle hydrocasts to about 250 m depth; Station 5B1 on the warm side, 5B2 in the middle, and 5B3 on the cool side. The casts were made two days after the BT passes. In this profile, only the 17°C isotherm was inverted. Another triplet of similar casts (station 5E1 (w), 5E2 (m), and 5E3 (c)), made a day after the first three, generated a profile lacking an inversion, though the 17°C isotherm was more than 10 m deeper at the middle station that at either lateral station. This apparent development, from the BT pass to the last triplet of hydrocasts, suggests that some mixing or redistribution of heat has taken place, but it should be noted that the three groups of observations were not all in exactly the same place, nor were they quite similarly related to the front at depth. They were all grouped in an area between latitudes 22°44' and 23° North, and longitudes 109°27' and 109°40' West. The profile based on the BT's taken for each hydrocast showed an inversion in the 17°C isotherm for the first triplet (B series) of casts, and in the 16°C isotherm for the second set (E series).

The salinity is the best indicator of the two kinds of water forming the front, judging from the salinity profiles of the two triplets of hydrocasts. All such profiles were drawn in the most objective way even though they were largely interpolated. All properties were drawn against the thermosteric anomaly first; isohalines were determined by the observations at the stations and by the intersections of specific isotherms and specific isosteres. The profiles of properties with depth were then derived from those of properties with thermosteric anomaly.

The detail imparted to the salinity profile by this method agrees strongly with the temperature structure seen on Fig. 5. Fig. 7 shows the salinity profile for the first triplet (B series) of hydrocasts. The 17°C isotherm from the corresponding temperature profile has been drawn on the salinity profile to show the close agreement between the cooler, lower salinity water and the warmer, higher salinity water. The salinity structure shown by the profile - complementary intrusions of the two kinds of water into each other - persisted almost unchanged till the later triplet (E series) of hydrocasts; the salinity profile of this later series (not given here) showed that the cooler, less saline water apparently moved farther into the warmer, more saline water, for it was observable as a pronounced salinity minimum at the "warm" station at about 30 m depth. The salinity-depth curves in Fig. 7 are based on the salinities observed and on those interpolated at standard depths. The curve for the warm side shows the marked influence of low-salinity water at about 30 m and 70 m depths; that is, above and below the prominent obtrusion of high-salinity water between 30 m and 70 m depths. The curve for the middle station shows that the two levels of salinity, characterizing the two types of water forming the front, are only mixed within a relatively narrow range of depth, because the curve is essentially like that of the cool side down to about 25 m depth and like that of the warm side from about 40 m to about 130 m where all three curves become practically the same. Above about 125 m these three curves resemble the T-S curves.

Although oxygen, nitrate-, and nitrite-nitrogen contents were measured for each cast-bottle sample, their profiles do not throw much further light on the structure of the front. The oxygen profiles qualitatively resemble the corresponding temperature profiles, except that the oxygen profile of the first (B) series of casts lacks the inversion found in the 17°C isotherm in the B series temperature profile. The nitrite profiles showed maxima: at about 25 m on the warm side in the first series of casts; at about 30 m on the warm and cool sides of the second series, with a somewhat lower value in the middle. The maximum on the warm side in the first series is a little shallower than the salinity maximum, but corresponds fairly well with the sharp salinity gradient. The nitrate profiles show maxima at greater depths than

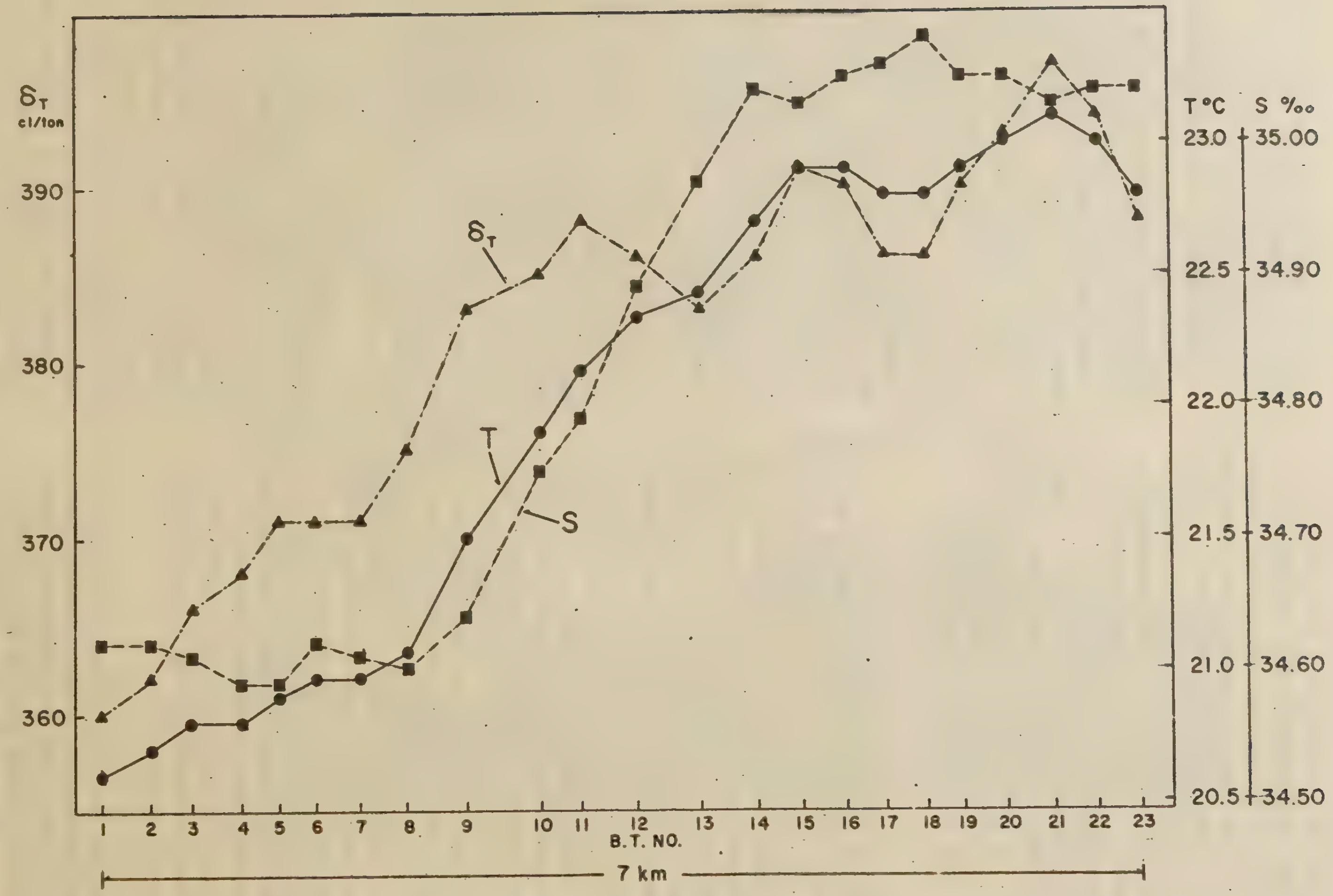

Fig. 6 Gradients of surface temperature (T), salinity (S), and thermosteric anomaly (δ_T), across front 5, from observations made with each BT lowering on BT pass no. 3 (Fig. 5).

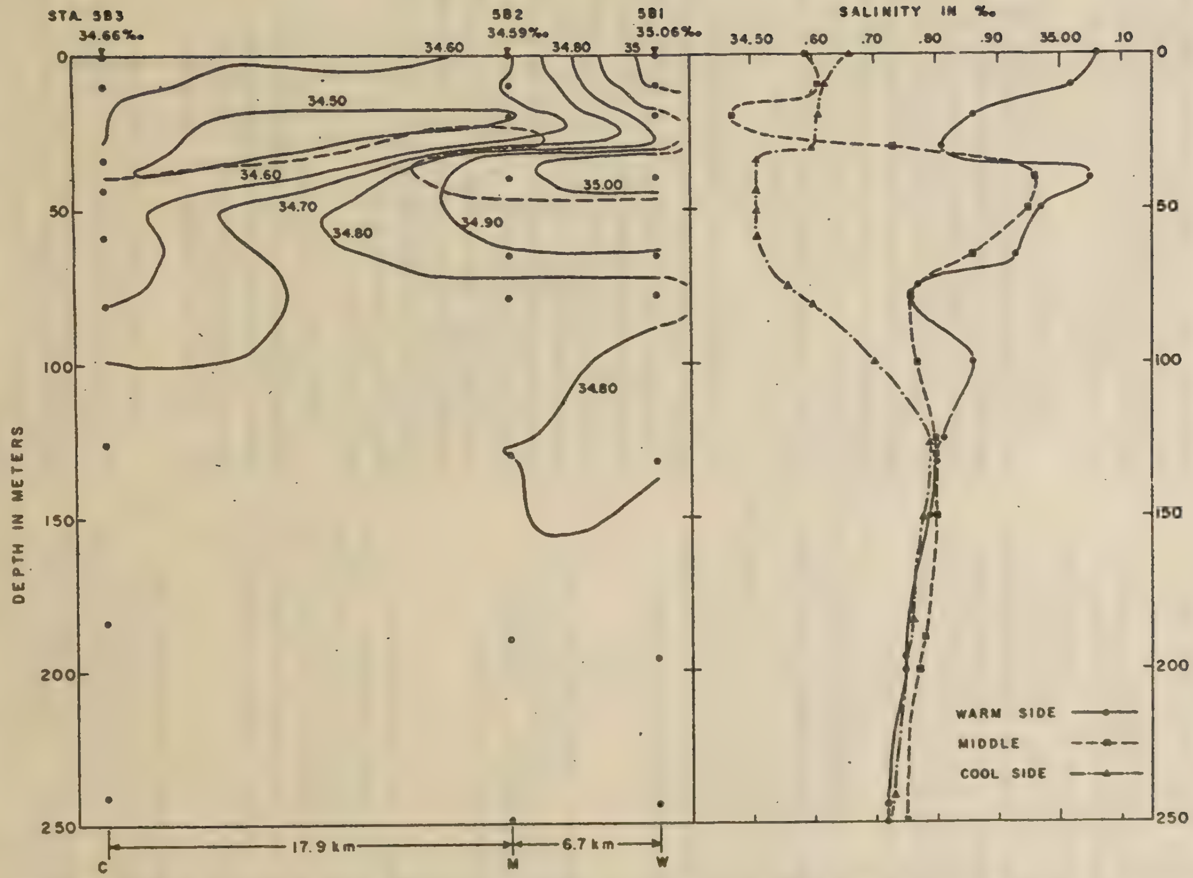

Fig. 7 The salinity profile and salinity-depth curves for the first (B) series of hydrocasts at front 5. Stations 5B1, 5B2, and 5B3 are on the warm side (w), in the middle (m), and on the cool side (c) of the front, respectively. The dotted contour is that of the 17°C. isotherm from the corresponding temperature profile, to show the relation of the temperature inversion to the salinity inversion.

those of the nitrate, as might be expected from the fact that nitrate succeeds nitrite in oxidative decay. The nitrate profiles also show other features that are not readily explained, but these are, conveniently, well below the frontal zone.

Most of the results from fronts 1, 2, and 4, besides being based on fewer and less coherent observations, do not permit any confident explanation. Apparently, Gulf water did not participate in them, unless it had been much modified. Even so, the most probable salinity structure that the data provide is not entirely different from that found at front 5. There was not, evidently, a simple interface between the warm and the cool water. The surface temperature difference across front 2 (10 May 1960) was similar to that across front 4(23 May 1960), and the actual values were similar: front 2 - 19.96° to 21.74°C: front 4 - 19.34° to 21.00°C.

This was surprising, considering that these two fronts were about two weeks apart; they were in almost the same place, however. Their respective T-S curves, for warm and cool sides, showed that a significant amount of change had taken place during the two weeks. The composition of their plankton on either side had also changed significantly.

These fronts far offshore were also moving faster than did fronts 3 and 5 (at Cape San Lucas) which made study of them difficult. For this and other reasons they will not be further considered here.

The results of biological observations at front 5 do not show any clear-cut patterns. Time did not allow us to make the density of observations so essential to obtaining significant biological results. The chief point of interest is whether this front (5) aggregates biota. Some results suggest that it does, others do not.

A triplet of Van Dorn plastic samplers was made at almost the same time as the first (B) series of hydrocasts. To avoid significant time delays, each cast consisted of only four samplers at 0, 25, 40, and 100 m depths. Therefore, the profile based on them (Fig. 8) cannot be considered quite reliable, even though it shows a marked maximum at the middle station at 25 m. A special cast to determine beam transmission and chlorophyll a at each meter of depth was made in the middle of the front at station 5E2 (second series of hydrocasts); this showed that chlorophyll a concentration changed markedly with small changes in depth. Owing to this fact, there is the possibility that maxima, such as that found in the middle of the front, existed also on either side, but that the wide-spaced bottles failed to sample these.

As it stands, the profile shows that maxima existed at all three stations, with the greatest in the middle. There the chlorophyll a concentration was approximately twice as great as that in the maxima at either station to the side. The profile maximum (0.66 mg. C per m^3) coincided with the high-salinity (S~34.90 °/oo) water (see Fig. 7).

The number of samplers per cast was minimized to ensure three things: i) that a cast, started in the middle of the front, did in fact sample "middle" water (at this time the structure of the front (5) at depth was not known because no data had been worked up); ii) that there was no marked time lag between the sampling of the warm side and of the cool side; iii) that water filters were freed of earlier samples in time for later ones.

Similar practical considerations, especially the great importance of eliminating difference in starting times of productivity experiments, confined our observations of productivity to the surface water. It usually took at least half an hour to cross the front (at 9 kt), and incubation of samples should start as close to local apparent noon as possible, because incubation should be for half a solar day for optimum results. The productivity at the surface increased on passing from the warm side to the cool; the values were: 6.87, 11.88, and 16.38 mg. C/m^2/day.

These two groups of results (chlorophyll a) indicating aggregation of phytoplankton in the front, the other (surface productivity) indicating a trend from one side to the other, characterize the remaining biological results.

Table II summarizes the results of net hauls made at front 5. All hauls were made along an isotherm (warm, middle or cool). The isotherm was noted from the thermograph and the vessel was allowed to drift; it usually drifted along an isotherm and the direction was noted (if possible) and used for the tow. The thermograph was checked during the tow to ensure that the haul did not pass into a less desirable kind of water.

To determine whether the front was a focus of biota, ratios of standardized volumes from one

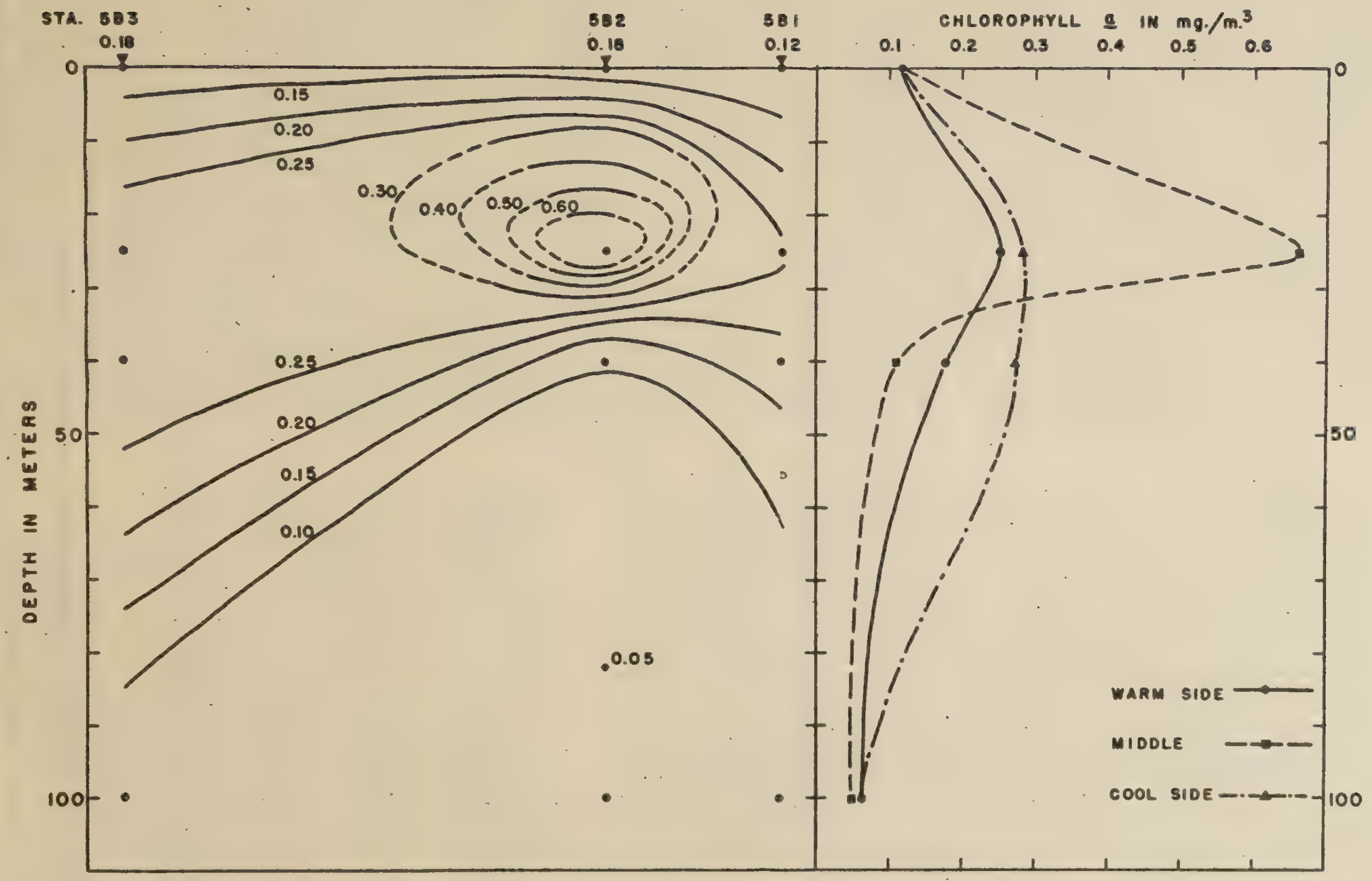

Fig. 8 The chlorophyll a profile and chlorophyll a - depth curves based on three Van Dorn plastic sampler casts at front 5. Stations 5B1, 5B2, and 5B3, correspond approximately to those on which the salinity profile (Fig. 7) was based.

haul to the next, across the front have been given (the volume for the warm side has been set at unity). It is assumed that if the front aggregates zooplankton, the volume in (the middle of) the front will be greater than that to either side. The sampling methods, which are quite standard, are open to criticism. The oblique hauls sample water below the frontal zone (depth>120 m). It is felt, however, that contributions from below the frontal zone are i) relatively independent of the front and not greater on one side than the other; ii) relatively small, because one set of hauls was taken at night when effects due to vertical migration would be minimal and the other was taken at dusk when these effects would be tending to a minimum (that is, the plankton would be mostly in the upper hundred meters). Most of the catch was, then, in the frontal zone and the relation of the catches to the front may indicate well enough the effect of the front on the biota. Another natural objection is that oblique hauls on either side of the front may sample parcels of water from the opposite side, by virtue of the Z-shaped interface (see Figs. 5 and 7). This is possible, but the data show that the cool side has a higher standing crop than the warm side; hence, if the haul on the warm side were sampling a significant amount of cool plankton-rich water, the observed differences would very likely be much less than they are.

From Table II we see that, according to the two sets of oblique hauls, the front aggregates zooplankton (ratios: 1.0 to 5.0 to 2.2; and 1.0 to 10.0 to 3.8). There is some suggestion that this is true of the Clarke-Bumpus samplers above the thermocline, but these nets sample so little water (about 70 m^3) that the differences are probably not reliable. These samplers were towed at three depths at a time on one wire; those below the thermocline failed in each haul.

Clarke-Bumpus samplers in the thermocline (bottom of mixed layer) show a trend of increasing volumes from the warm into the cool water.

The surface (horizontal) hauls also show increasing volumes towards the cool side, the ratios (1.0 to 3.4 to 8.7) being significant. Significance has not been tested statistically; the rough rule that differences of half or double a given value are significant, has been used. This rule, derived from studies by Winsor and Clarke (1940) and Silliman (1946), was based on counts and not volumes, but it is useful as a conservative rule-of-thumb.

Nekton-net hauls, the catch of which is largely micronekton (minimum linear dimension of 5 cm), show increasing values on passing from the cool to the warm side. It is supposed, of course, that the nekton would not be directly (mechanically) aggregated by the front, though it might accumulate there by preference; note that the micronekton components of the other net hauls have been given in Table II. The zooplank component of the nekton hauls, mostly relatively large euphausiids (about cm long), was much greater in the middle and on the cool side of the front. This element of the biota was not apparently caught by any of the nets except this big nekton net which samples only to a depth of 115 m at the most (Blackburn and associates 1962

Aliquots of each sample were sorted and the numbers of the predominant groups counted; the volumes of the most abundant of these groups we measured by the method of Yentsch and Hebard (1957). Table III shows the ratios of counts (star dardized to the full sample and to 10^3 m^3 of wate strained), for qualitative comparison with volum ratios given in Table II. The following ratios ar of particular interest: i) those showing much hig values in the middle of the front - euphausiids in both series (A and F) of oblique hauls, pteropods the first (A) series of oblique hauls (the second (had a large number only on the cool side), copep and chaetognaths in the second (F) series of obli hauls and the Clarke-Bumpus hauls above the thermocline; ii) those showing much higher values on the cool side only - copepods, euphaus pteropods and chaetognaths in the surface (D) se of hauls, fish and stomatopod larvae in the nekt (D) hauls; iii) those showing much higher values on the warm side - red crab larvae in the Clarke Bumpus hauls in the thermocline, red crab adult and prawns (shrimps?) in the nekton hauls; iv) those showing very low values in the middle chaetognaths in the Clarke-Bumpus haul in the thermocline; v) those showing high values on th cool side and in the middle - euphausiids in the nekton (D) hauls. These results will not be analyzed further in this paper. The use of indicator organisms to determine water masses awaits further study, but should prove most help ful. Evidently, some groups are considerably more abundant than others, in relation to the fr and it is doubtful that even accidents of sampling can account for this. Nevertheless, no consist pattern is evident, and much more sampling is needed to determine with certainty whether this (convergent) front physically aggregates the pla Another difficulty, which might be diminished by

Table II

Results of net hauls made at the Cape San Lucas Front (front 5)

Station	Time of day	Depth of tow	Vol. plankton per $10^3 m^3$	Ratio of volumes	Vol. micronekton[3] per $10^3 m^3$	Ratio of volumes	Dominant forms: Zooplankton (by vol.&/or number)	Micronekton[3]
OBLIQUE 1m NET HAULS								
5A1 (w)[1]	n[2]	300	20	1	95	1	copepods, chaetognaths, ostracods	red crabs
5A2 (m)[1]	n	261	101	5.0	3	0.03	copepods, euphausiids, pteropods	
5A3 (c)[1]	n	329	43	2.2	158	1.7	copepods, pteropods, euphausiids, ostracods	red crabs
5F1 (w)	d[2]	200	20	1	120	1	copepods, chaetognaths	red crabs
5F2 (m)	d	170	199	10.0	1638	13.7	euphausiids, copepods	red crabs
5F3 (c)	d	321	75	3.8	12	0.1	copepods, chaetognaths, pteropods, siphonophores	red crabs
HORIZONTAL 1m NET HAULS								
5D2 (w)	n	3	52	1	46	1	copepods, chaetognaths, pteropods	a large salp
5D3 (m)	n	3	179	3.4	0	-	chaetognaths, copepods, pteropods, siphonophores	
5D1 (c)	n	3	452	8.7	52	1.1	copepods, pteropods, siphonophores	salps
HORIZONTAL CLARKE-BUMPUS NET HAULS i) ABOVE the thermocline								
5C1 (w)	d	15	7	1	0	-	copepods, chaetognaths, pteropods	
5C2 (m)	d	20	78	11.1	0	-	chaetognaths, copepods	
5C3 (c)	d	15	58	8.3	0	-	euphausiids, copepods, siphonophores	
ii) IN the thermocline								
5C1 (w)	d	40	59	1	0	-	red crab larvae, chaetognaths, copepods	
5C2 (m)	d	35	63	1.1	0	-	euphausiids, red crab larvae, copepods	
5C3 (c)	d	25	127	2.2	0	-	euphausiids, copepods, chaetognaths	
OBLIQUE 5ft x 5ft NEKTON NET HAULS								
5D2 (w)	n	100	0.1	1	66	1		red crabs, fish, prawns
5D3 (m)	n	100	5	50	9	0.14	euphausiids	red crabs, fish
5D1 (c)	n	100	5	50	8	0.12	euphausiids, stomatopod larvae	fish

[1] See Table I.

[2] n = night; d = dusk.

[3] Micronekton is, roughly speaking, a small organism of minimum linear dimension 5 cm. and of maximum linear dimension of, say, 15 cm.

Table III

Ratios of major groups of organisms in the net hauls made on the warm side, in the middle, and on the cool side of the Cape San Lucas Front (front 5). The ratios are of the counts, and the count of the warm side is set at unity. Ratios are only given when a group was represented in all catches of a triplet.

OBLIQUE HAULS.

Organisms	Sta. 5A1 (w)	5A2 (m)	5A3 (c)	Sta. 5F1 (w)	5F2 (m)	5F3 (c)
Copepods	1.0	1.7	0.8	1.0	5.6	2.2
Euphausiids	1.0	7.9	4.0	1.0	11.0	2.5
Pteropods	1.0	24.7	11.6	-	-	-
Ostracods	1.0	1.2	0.9	-	-	-
Chaetognaths	1.0	0.5	0.4	1.0	4.5	2.6
Average	1.0	2.3	1.2	1.0	7.2	2.4
Total plankton volumes	1.0	5.0	2.2	1.0	10.0	3.8

HORIZONTAL HAULS

i) SURFACE; ii) CLARKE-BUMPUS: a) ABOVE thermocline

Organisms	Sta. 5D2 (w)	5D3 (m)	5D1 (c)	Sta. 5C1 (w)	5C2 (m)	5C3 (c)
Copepods	1.0	1.4	6.1	1.0	6.0	1.2
Euphausiids	1.0	2.1	5.2	-	-	-
Pteropods	1.0	3.2	27.0	-	-	-
Chaetognaths	1.0	1.8	1.6	1.4	14.0	1.1
Siphonophores	1.0	2.1	4.9	-	-	-
Average	1.0	2.1	9.0	1.0	10.0	1.1
Total plankton volumes	1.0	3.4	8.7	1.0	11.1	8.3

b) IN thermocline

Organisms	Sta. 5C1 (w)	5C2 (m)	5C3 (c)
Copepods	1.0	0.8	1.8
Red crab larvae	1.0	0.5	~0
Chaetognaths	1.0	0.1	0.8
Average	1.0	0.5	0.9
Total plankton volumes	1.0	1.1	2.2

OBLIQUE HAULS

NEKTON

	Sta. 5D2 (w)	5D3 (m)	5D1 (c)	
Red crab adults	1.0	0.04	~0	
Prawns	1.0	0.08	-	
Fish	1.0	0.3	4.0	
Leptocephalus	1.0	1.2	1.8	
Squid	1.0	3.0	2.7	
Euphausiids	1.0	73.2	64.8	} plankton
Stomatopod larvae	1.0	0.8	11.3	
Average	1.0	11.2	12.1	
Total volumes	1.0	0.2	0.2	

further close inspection of the data to hand, is that of grazing; the rate may well be different in the middle from what it is on either side, and could affect the results of net hauls significantly. My tentative view, however, is that aggregation here is more likely to occur than not, but may well be masked to some extent by the relatively greater contribution of cool-water biota at this time (spring, the upwelling season) of the year. The standing crop of zooplankton at front 2 was about three times greater on the cool side than on the warm; the values were roughly the same on either side of front 4, however.

Front 5, as noted earlier, was not visible on the sea surface, and although the sea state changed from calm to choppy as the vessel moved offshore from the lee of the land mass, this fairly rapid change was not related, directly at least, to the front. The front was therefore in calm waters, and, in these, marlin were especially abundant. A few small sport-fishing boats had successful fishing while we were there. Birds were not particularly abundant.

No tuna or tuna-fishing vessels were sighted during the work at front 5 (19-24 April, 1961); a few schools of tuna (species unindentified) were sighted near the Tres Marias Islands on cruise TO-60-1 (May 1960), but no tuna-boats were seen. Fig. 9 and 10 show the distribution of catch (of yellowfin) and effort by purse-seiners in and near the Gulf entrance in May 1960 and April 1961, respectively, corresponding to the months of the cruises TO-60-1 and TO-61-1. The data were kindly supplied by the Inter-American Tropical Tuna Commission. No conclusions are drawn from these two Figures at present, but a comparison of Figures 1 and 9 is of interest.

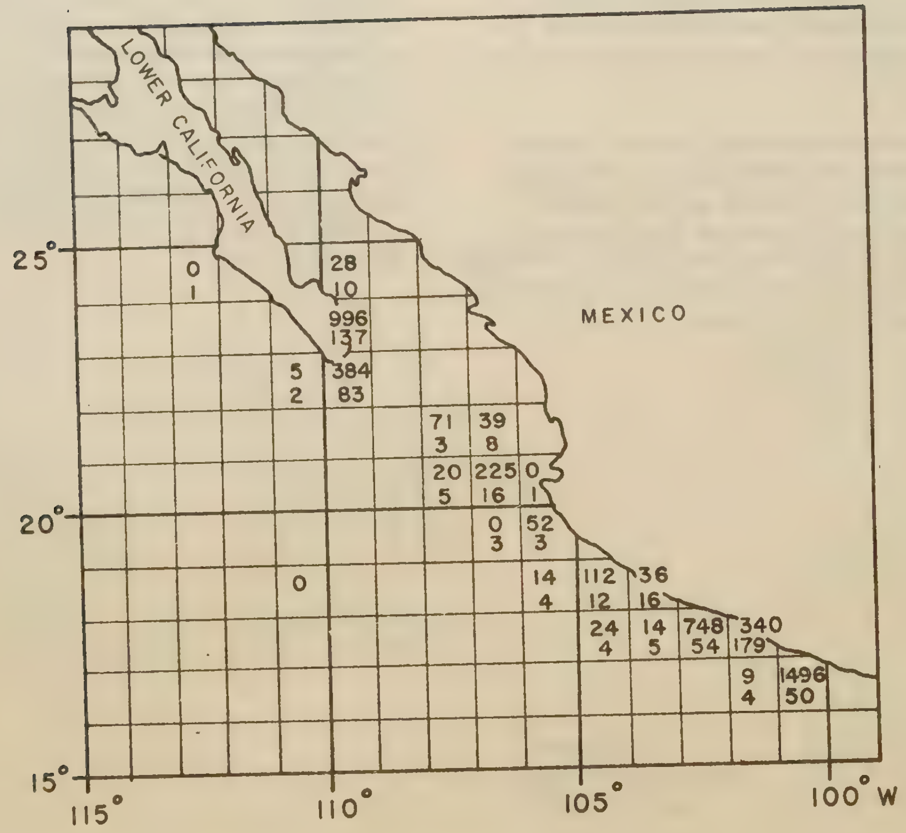
LOWER CALIFORNIA
MEXICO
25°
20°
15°
115°
110°
105°
100° W
0
1
28
10
996
137
5
2
384
83
71
3
39
8
20
5
225
16
0
1
0
3
52
3
0
14
4
112
12
36
16
24
4
14
5
748
54
340
179
9
4
1496
50

Fig. 9 Distribution of effort by purse-seiners and their catch of yellowfin, in May 1960, by one-degree squares, off western Mexico and Lower California. The upper figure in each square is the catch in tons, the lower figure is the corresponding effort in standardized boat-days.

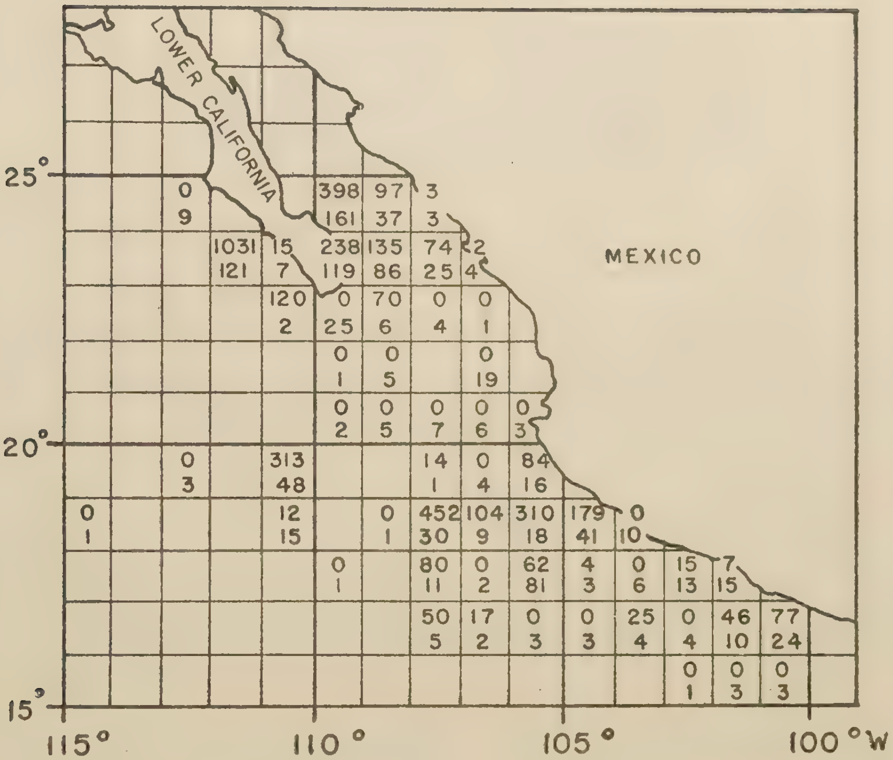
LOWER CALIFORNIA
MEXICO
25°
20°
15°
115°
110°
105°
100°W
0 9
398 161
97 37
3 3
1031 121
15 7
238 119
135 86
74 25
2 4
120 2
0 25
70 6
0 4
0 1
0 1
0 5
0 19
0 2
0 5
0 7
0 6
0 3
0 3
313 48
14 1
0 4
84 16
0 1
12 15
0 1
452 30
104 9
310 18
179 41
0 10
0 1
80 11
0 2
62 81
4 3
0 6
15 13
7 15
50 5
17 2
0 3
0 3
25 4
0 4
46 10
77 24
0 1
0 3
0 3

Fig. 10 Distribution of effort by purse-seiners and their catch of yellowfin, in April 1961, by one-degree squares, off western Mexico and Lower California. Upper figure in each square is the catch in tons, the lower figure is the corresponding effort in standardized boat-days.

Experience Paper No. 34

STUDIES OF OCEANIC FRONTS IN THE MOUTH OF THE GULF OF CALIFORNIA, AN AREA OF TUNA MIGRATIONS

By

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Abstract

A review of the literature shows that it is widely believed that small biota (e.g. plankton, micronekton) and pelagic fish tend to be especially abundant at fronts, but few detailed studies of this have been made. The present paper shows the distribution of physical and biological oceanographic properties at certain fronts in a region through which tuna migrate.

Fronts in the mouth of the Gulf of California may be formed, in the upper 120 m, by two of three types of water: (i) Gulf of California; (ii) California Current; (iii) equatorial Pacific. The front best developed and studied is off Cape San Lucas, Lower California, in spring and summer; the cool, low-salinity, upwelled water contrasts well with the warm, saline Gulf water. Vertically, this front has a Z-shaped interface.

Biological property distributions show that certain kinds of biota were more numerous in the middle of this front than on either side, and may therefore have been accumulated by convergence at the front. Marlin were observed in the area at the time of the observations, but tuna were not. Commercial catch and effort data on yellowfin are available by one-degree rectangles and by months, but this scale is too gross to show any clear relation to the front.

ETUDES DES FRONTS OCEANIQUES A L'ENTREE DU GOLFE DE CALIFORNIE, ZONE DE MIGRATION DU THON

Résumé

L'examen de la bibliographie montre que l'abondance particulière sur les fronts océaniques de petits biota et de poissons pélagiques est une idée très largement répandue, mais qu'il y a peu d'études de détail à ce sujet. Cet article traite de la distribution des propriétés océanographiques, physiques et biologiques, sur certains fronts dans une zone où migrent les thons.

Les fronts à l'entrée du golfe de Californie peuvent être formés dans les 120 m supérieurs par deux de trois types d'eaux: (i) golfe de Californie, (ii) courant de Californie, (iii) Pacifique équatorial. Le front le plus développé et le mieux étudié

est au large du Cap San-Lucas, Basse Californie, au printemps et en été; l'eau de remontée, froide et de faible salinité, contraste nettement avec l'eau chaude et salée du golfe. Sur le plan vertical ce front présente une interface en forme de Z.

La distribution des propriétés biologiques montre que certains types de biota sont plus nombreux dans la partie médiane de ce front que sur les autres côtés et pourraient avoir été accumulés en conséquence par une convergence sur ce front. On a noté la présence de marlin dans cette zone au cours des observations, mais non celle du thon. On dispose de données sur le volume de capture et sur l'effort de pêche dans des rectangles d'un degré et par mois, mais cette échelle est trop large pour qu'on puisse déceler une relation nette avec le front.

ESTUDIOS DE LOS FRENTES OCEANICOS EN LA BOCA DEL GOLFO DE CALIFORNIA, ZONA DE EMIGRACIONES DEL ATUN

Extracto

Un examen de la literatura revela que está muy difundida la idea de que la biota pequeña y los peces pelágicos tienden a abundar especialmente en los frentes oceánicos, pero de ello se han hecho pocos estudios profundos. En esta ponencia se da a conocer la distribución de propiedades oceanográficas físicas y biológicas en ciertos frentes de una región por la que emigra el atún.

En la boca del Golfo de California pueden formar frente, en los 120 m. superiores, dos de tres clases de agua: (i) del Golfo de California; (ii) de la corriente de California; (iii) del Pacífico ecuatorial. El frente más claro y mejor estudiado es el del Cabo San Lucas, Baja California, en primavera y verano; el agua de surgencia fría y de baja salinidad contrasta con la cálida y salina del Golfo. Verticalmente este frente tiene una superficie en forma de Z.

La distribución de las propiedades biológicas demuestra que ciertas clases de biota son más numerosas en el centro que en los lados de este frente y es posible, por lo tanto, que se hayan acumulado por convergencia. Al hacerse las observaciones se vio pez aguja en la zona, pero no atunes. Se dispone de datos de captura industrial y de esfuerzos de pesca de atún de aleta amarilla en rectángulos de un grado y por meses, pero esta escala es demasiado grosera para mostrar una relación clara con el frente.

1 INTRODUCTION

The most prominent oceanographic features of the entrance to the Gulf of California, though they vary considerably in time, space, and intensity, are oceanic fronts, found usually near Cape San Lucas at the southern end of Lower (Baja) California and sometimes at Cape Corrientes (Fig. 1).

There is no precise definition in oceanography of the term "front", which has apparently been widely adopted from meteorologists. Cromwell and Reid (1956) say "A front will mean a band along the sea surface across which density changes abruptly". This definition has the advantage that it does not particularize the more readily measured properties (temperature and salinity) that determine the density change. As a rule, assuming that the front is not visible, it is best indicated by a thermograph. It is quite possible for the density change to be due entirely to salinity differences, however. This leads to the use of such terms as temperature fronts and salinity fronts.

Uda (1959) appears to take the view that a front (siome) is a boundary between two different kinds of water. He says, "Then the boundaries of the water mass are in the region where the gradients of the property are maximum (i. e. the Polar Fronts, etc.)".

La Fond (1961) uses the following definition: "The leading edge of a border separating unlike water masses is called a front. Fronts can occur not only between water masses of different salinity but also between those differing in other properties, such as temperature".

The term "water mass" in these definitions is used loosely, not necessarily in conformity with Sverdrup, Johnson, and Fleming (1942). For example, fronts are often found between upwelled water and non-upwelled water, both kinds pertaining to one water mass in the sense of Sverdrup et al.

Uda (1959) specifies a front, in terms of a temperature gradient, as varying from 0.5°C/10 miles to 5.0°C/10 miles. This tenfold difference between limits illustrates the inevitable lack of precision in any definition of an oceanic front.

The best known fronts (perhaps better called frontal systems, using the word front for sections of those systems that we investigate) are those between the cool, low-salinity polar waters and the warm, more saline, subtropical waters: the Arctic and Antarctic Convergences; and those between the Equatorial Counter-current and the North and South Equatorial Currents. Lesser known but important fronts occur between the Baltic outflow and the North Sea; between the outflow from the Gulf of California and the California Current and/or equatorial Pacific waters; and in regions of upwelling. These few examples cover a wide range of dimension and motion, and cannot be freely compared amongst themselves; they represent only a small selection of all known frontal areas (see Uda 1938). The zone of mixing between the Kuroshio and the Oyashio (and between the Gulf Stream and the Labrador Current) is so vast in certain times and places that some workers refer to the front between Kuroshio and mixed water as the Kuroshio front, and to that between the Oyashio and the mixed water as the Oyashio front; a similar distinction may be made in the western Atlantic where the mixed water is called Shelf water.

Important contributions to the knowledge of the front between the Kuroshio and the Oyashio have been made by Beklemishev and Burkov (1958); Burkov and Arseniev (1958); Fukuoka (1955); Hanzawa (1952); Kawai (1955); Masuzawa (1955a, 1955b); Siomina (1958); Uda (1938, 1943, 1953, 1954, 1955, 1958, 1959, 1961); Uda and Ishino (1958); and others. Important work on the Gulf Stream front has been done by Ford and Miller (1952); Fuglister (1951); Fuglister and Worthington (1951); Iselin and Fuglister (1948); Spilhaus (1940); Von Arx, Bumpus and Richardson (1955); and many others. The equatorial frontal systems have been studied by Austin (1960); Cromwell (1953, 1958); Cromwell and Reid (1956); King and Hida (1957); and others. Wyrtki (1960a, 1960b) and Mackintosh (1946) have contributed significantly to the understanding of the Antarctic polar front.

Although fronts are common off the coast of California and Lower California (as off any coast where upwelling is strong), study of them has been casual and incidental to the quasi-synoptic surveys of the whole region made by the California Co-operative Oceanic Fisheries Investigations (Cal. C. O. F. I.).

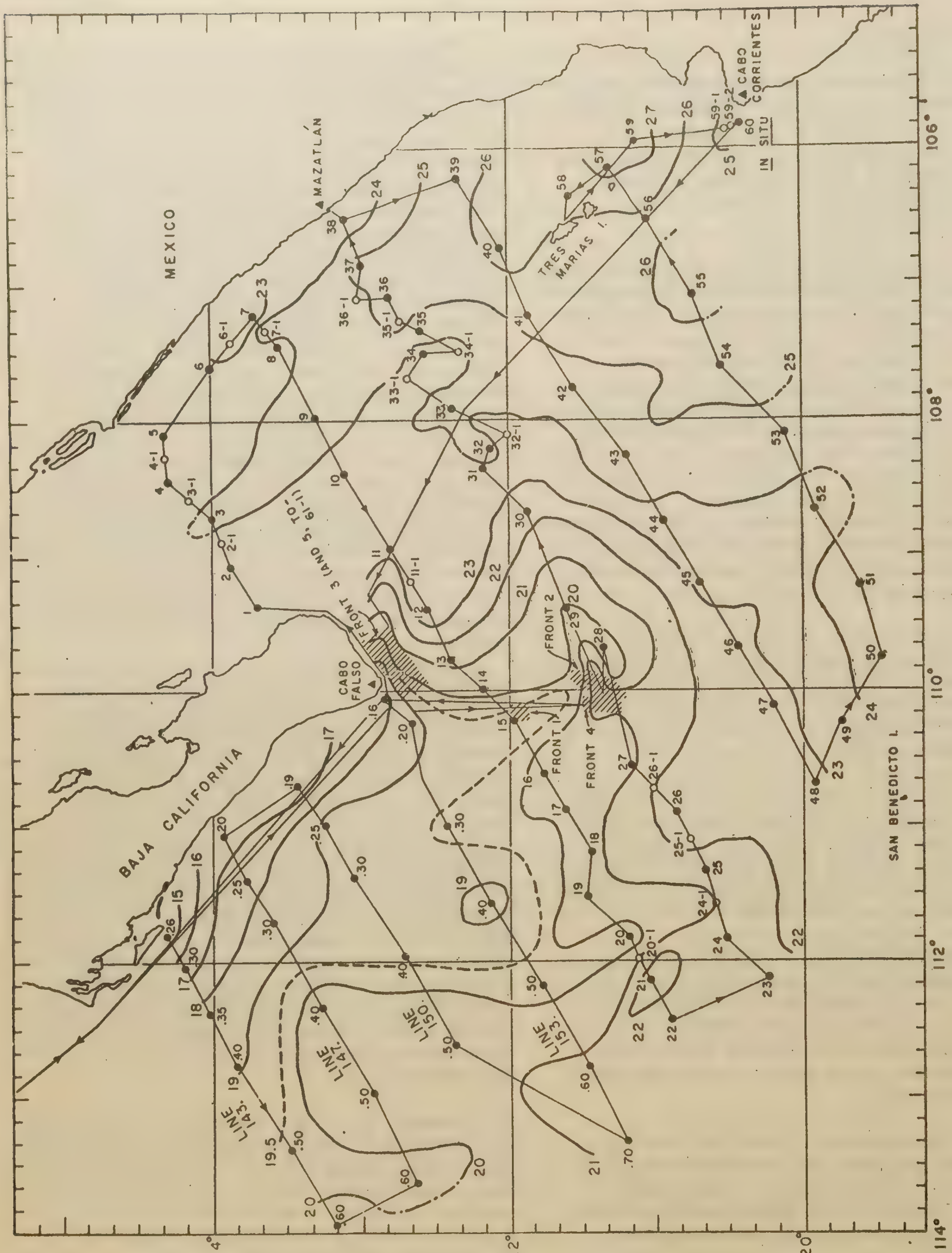
MEXICO
MAZATLÁN
BAJA CALIFORNIA
CABO FALSO
CABO CORRIENTES
TRES MARIAS I.
SAN BENEDICTO I.
FRONT 1
FRONT 2
FRONT 3 (AND 5, 61-1)
TO-1
FRONT 4
LINE 143.
LINE 147.
LINE 150.
LINE 153.
IN SITU
24°
22°
20°
114°
112°
110°
108°
106°

Fig. 1 A map showing the track of the S. T. O. R. cruise TO-60-1 (stations 1 to 60) and part of the track of Cal. C. O. F. I. cruise 6004B (stations 143.26 - 153.16). Stippled areas show where fronts were studied on TO-60-1 and TO-61-1. Surface isotherms (°C) have been superimposed.

The view that convergent fronts aggregate plankton is apparently rather widely held. Uda (1938) describes the accumulation of flotsam at siome, or fronts, and Uda and Ishino (1958) indicate that convergent fronts show a line of biological demarcation owing to aggregation of biota. They go on to show the relationship of fisheries for albacore (*Germo germo*), skipjack (*Katsuwonus pelamis*) and bluefin (*Thunnus orientalis*) to the front between the cool Oyashio and the warm Kuroshio. La Fond (1961) continuing his definition, started above, says, "These fronts raise water of higher nutrient content to the surface. In addition, the fronts tend to concentrate floating fish food in adjacent areas". This raises the question of whether a front manifests a higher standing crop of plankton than does water on either side by aggregating the biota or by causing conditions specially favorable to the growth of a higher standing crop. This, in turn, probably depends on whether the front is convergent, in which case aggregation might be expected, or divergent, in which case nutrient-rich water might be brought to the surface to increase plankton growth. Uda (1959) suggests that the latter occurs at siome (p. 18 *op. cit.*) although those he discusses are apparently of the convergent type. Evidently, there is some conflict of possibilities. Siomina (1958) states that phytoplankton "blooms" are a feature of the area of mixing between the Kuroshio and Oyashio; whether these "blooms" are the result of *in situ* production or of mechanical aggregation is not stated. Perhaps both causes are responsible, with the *in situ* production being the more important.

King and Hida (1957) show, on a relatively large scale, a relation between high standing crop of zooplankton and the frontal system in the central equatorial Pacific, without, however, establishing the actual cause of the high plankton values. Indeed, the peak values are slightly south of the three fronts (parts of the system) they studied. Their results also show a somewhat lower quantity of plankton in the convergence zone (2° - 4° N) than in the divergence zone (2° S - 2° N). Beklemishev and Burkov (1958) show, from data obtained by the R/V *Vitiaz*, that plankton is more abundant in the zone of contact between the Oyashio and the Kuroshio than to either side, and that this plankton comprises forms from both biotopes (cool, low-salinity and warm, high-salinity). The zone of mixing is about four hundred miles wide, however, in the area studied. These authors further say: "The quantity of species in the zone of mingling of water masses sometimes turns out to be greater than each separately (Siomina 1957)". [1]

Some relatively precise results, kindly lent me by Mr. T. S. Austin of the United States Fish and Wildlife Service, show catches of zooplankton hauls within five to ten miles of a front in the equatorial central Pacific. The highest catches were in the front and on the warm side (about five miles away); the volumes fell off beyond that but were roughly the same five miles away on the cool side and ten miles away on the warm side. Again, these data do not indicate the cause of the plankton distribution. Knauss (1957), writing of a front apparently between South Equatorial Current water and Equatorial Counter-current water, says, "High biological activity was associated with the front; however, there was no floating debris. The cold water was relatively sterile; most of the life appeared to be concentrated in the relatively narrow frontal zone". These biological observations were made only by dipnet.

There is a definite relation between fish abundance and fronts, according to Uda (1953, 1954, 1959 and 1961). Japanese fisheries for bluefin, albacore and skipjack are closely related to the front between the Oyashio and the Kuroshio (Uda and Ishino 1958). The local Japanese whale fishery is also related to this large frontal system (Uda 1938, 1954). The front between the Gulf Stream and the Labrador Current is not the focus of intense fishing such as there is off Japan, perhaps because fisheries are well developed on the larger continental shelf in the western Atlantic. Nevertheless, tuna are strongly associated with the Gulf Stream front (Walford 1958; Rivas 1955).

Eggvin (1940) discusses the advance of a cold front of Baltic water through the Skagerrak, northwards along the Norwegian coast in the early spring; this is an example of a negative relationship, however, for the cold, low-salinity water drives spawning herring (*Clupea harengus*) offshore and out of their usually favored habitats; this phenomenon varies from year to year, causing annual fluctuations in the recruitment. Robins (1952) shows a marked increase in troll catches of skipjack tuna in a front (a relatively weak one) in the entrance to Storm Bay, Tasmania.

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[1] These authors do not give a publication by Siomina for 1957 in their literature citations, but do give one by him for 1958, which seems to be appropriate to their statement. This is included in the literature cited for the present paper.

Although fronts have commanded the interest of oceanographers in general, relatively little detailed work has been done on them (disregarding the large-scale studies of the major frontal systems), especially from a biological point of view. The investigations already mentioned are overwhelmingly physical and dynamical. Quantitative biological measurements in relation to fronts, especially of the smaller, sharper kind, are scant in the literature.

The fronts studied by Scripps Tuna Oceanography Research group (S. T. O. R.) are described below. They have two points of general interest: i) they have, judging from the literature, been more completely studied than any others (though not necessarily in any particular detail); ii) they occur in an area that yellowfin (Neothunnus macropterus) and possibly skipjack tuna normally migrate across at a time of year when the fronts are best developed. Hence, these studies contribute to our knowledge of a relatively ill-known phenomenon; and the fronts may have an influence on the seasonal movement of tuna into the "local banks" fishery off the west coast of Lower California, though we do not know this yet.

A manuscript describing in detail the fronts studied by the S. T. O. R. group is being prepared for publication in the Special Scientific Report - Fisheries Series of the United States Department of the Interior, Fish and Wildlife Service. Many figures and data from that manuscript that cannot be presented in this paper are drawn upon freely here for the purpose of discussion.

2 OCEANOGRAPHIC CRUISES

S. T. O. R. cruise TO-60-1 (30 April – 27 May, 1960) was made to study the physical, chemical and biological properties of the entrance to the Gulf of California at a time when, normally, yellowfin and possibly skipjack tuna are migrating from the west coast of the Mexican mainland across or into the Gulf of California and thence to the west coast of Lower California (Alverson 1960; Griffiths 1960; Inter-American Tropical Tuna Commission Annual Reports, 1960 and 1961). Complementing this survey was a study of oceanic fronts known to be common there (Reid, Roden and Wyllie 1958; Roden and Groves 1959).

Using the experience gained in the observation of the four fronts studied on TO-60-1, further study was made of one of them (at Cape San Lucas) at the end of S. T. O. R. cruise TO-61-1 (19 - 24 April, 1961). The results obtained from this latter study form the body of this paper.

Apart from the S. T. O. R. cruises to the mouth of the Gulf, there are a number of Cal. C. O. F. I. cruises which went either into the Gulf or down to Cape San Lucas; these have been used to gain an idea of the variation in time and space of the Cape San Lucas front. These cruises, numbered by year and month, with Scripps Data Report references, are: 5011 (51-47), 5109 (51-38), 5401 (58-38), 5412 (60-1), 5501 (59-36), 5502 (59-36), 5503 (59-37) 5512 (60-4), 5601 (60-5), 5602 (60-5), 5604 (60-6), 5612 (61-22), 5702 (58-22), 5704 (58-24), 5706 (58-33), 5708 (58-63), 5801 (59-3), 5908 (61-19), 6001 (61-23), and 6004 (62-6). Data from the Vermilion Sea Expedition, 13 April to 29 May, 1959 (60-51), were also used.

3 RESULTS

3.1 The General Area

Fig. 1 shows the track of cruise TO-60-1 and part of Cal. C. O. F. I. cruise 6004 (MV Black Douglas), which ended at Cape Falso (about 3 mi west of Cape San Lucas) on 30 April 1960. The surface isotherms and areas in which fronts (1, 2, 3, 4 and 5) were studied are superimposed. The striking features are: i) the frontal system formed by the 20°, 21°, 22° and 23°C isotherms, extending from the southern tip of Lower (Baja) California roughly southwards for about 100 mi then turning westwards, eventually becoming weaker; fronts were found within this system ii) the strong indication of upwelling inshore along the west coast of Lower California, with apparent southward transport of the upwelled water; iii) the intrusion of warm water (24°, 25°, and 26°C isotherms) into the Gulf along its eastern side. This distribution of surface temperatures agrees qualitatively with those drawn from the data of Cal. C. O. F. I cruises 5604 and 5704 (both in April, like TO-60-1) and from the Vermilion Sea Expedition (April to May 1959). The configuration of the isotherms at the surface, on TO-60-1, persisted more or less to a depth of about 50 m, but became modified below that depth. Most of the data of TO-60-1 have been processed and drawn, and form the basis for some of the present discussion. For economy of space such drawings have not been figured.

The isohalines agree qualitatively with the isotherms, confirming that the frontal system is formed from warm, saline water to the east and cool, less saline water to the west and northwest; the salinity contours also persist to at least 50 m deep. Horizontal contours of most of the other properties substantiate this picture. Even so, vertical profiles, especially of salinity, between stations 7 and 22, and 23 and 38, show that the area is a very complicated one in the upper 100 m.

Our investigation of fronts has been, then, the study of very small sections of a rather large frontal system; it is an assumption that what was found applies more or less to the whole system. Moreover, the sections studied have shown much more intense gradients than appear in Fig. 1, but this is certainly a function of the density of observations in time and space.

3.2 The Fronts

Quite the best front, from the standpoint of oceanographic study, is that immediately offshore from Cape San Lucas (fronts 3 and 5, Fig. 1). This is because the land protects the sea surface from the prevailing northwest winds which would, and do out to sea, mix the surface waters. (Thermocline depth is much greater out to sea than in the mouth of the Gulf). The mixing has, for instance, made it rather hard to decide confidently what kinds of water formed fronts 2 and 4. Front 1, judging from the temperature regime (Fig. 1), was between upwelled water and non-upwelled water in the California Current system.

Fig. 2 shows the distribution of surface isotherms as derived from the initial thermograph survey (19 to 20 April, 1961) of front 5. The high node ($T > 23^{\circ}C$) to the north and east, and the intrusion of cool water ($T < 20^{\circ}C$) from the west, are the chief features; the front is formed between the warm and the cool waters. This fundamental plan was still present five days later when a final thermograph survey (23 to 24 April) was made (Fig. 3); the warm water had, however, moved westwards inshore, while the cool water had moved eastwards offshore, the front being maintained between them (Fig. 3). Other fronts out to sea (1, 2 and 4) were much faster moving and less stable, and therefore harder to study.

Perhaps more gratifying than the stability of this front was its fundamental similarity to front 3 which was in the same area eleven months earlier (22 May, 1960). Fig. 4 shows the surface isotherms of front 3; the warm water west of the node ($T > 25^{\circ}C$) appears to have moved westwards cutting across cool water coming from the north and separating a parcel of it to form an eddy south of the front roughly opposite the warm node. Such a situation could arise from that found at front 5, which makes us think that fronts 3 and 5 are basically alike. Unfortunately, circumstances did not allow us to study front 3 further.

The westward movement of warm water at front 5 was shown by four drogues, two with parachute at 5 m depth and two with them at 50 m. These were put into the water near the middle or slightly towards the warm side of the front on the afternoon of 21 April, about 12 mi southeast of Punta Palmilla. All were observed till lost: two, one of each kind, for about 39 hours, two for about 51 hours. The southernmost one (nearest the cool water) moved first a little northwest, then southeast, and finally north, before being lost. The other three all moved first north, then roughly west, in warm water. These drogue movements are clear evidence of the westward movement of warm water inshore.

A G.E.K (Geomagnetic ElectroKinetograph) survey was made at the northeastern part of front 5 where it bends from an east-west line to a north-south one (see Figs. 2 and 3), about 10 mi southeast of Punta Palmilla. This survey showed that warm (surface) water was moving roughly southwest at 10-30 cm/sec. Two observations (no. 4 and 9 in Table I), in the bend in the front, showed that cool water was moving slowly eastwards.

The indication by the G.E.K. of water moving out of the mouth of the Gulf is in full accord with the view of Roden and Groves (1959) that surface water generally leaves the Gulf on its western side. They state that maximum transport is at about 50 m depth.

Having established the orientation and movement of the front, we then investigated it at depth. Three BT (BathyThermograph) passes

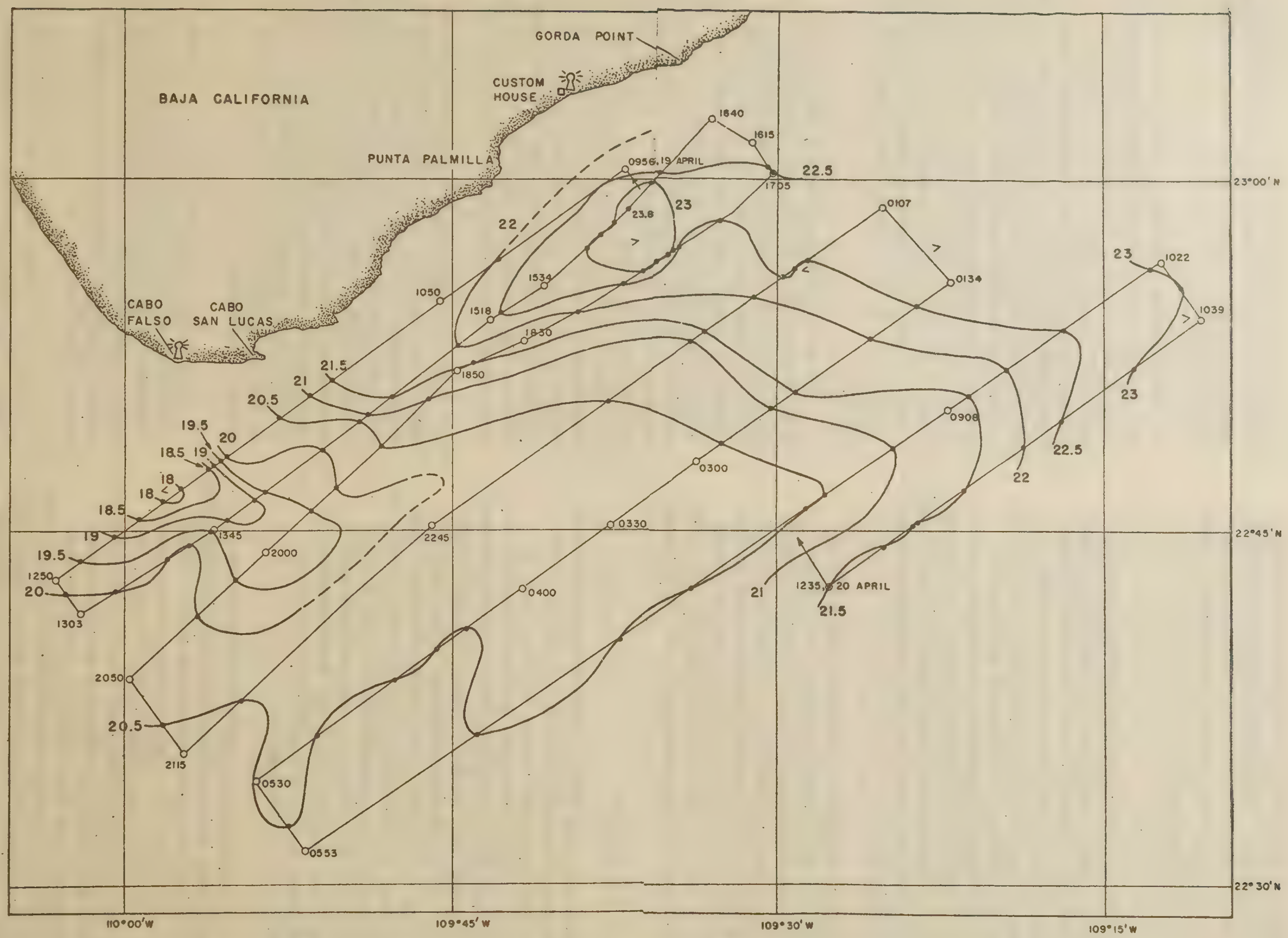
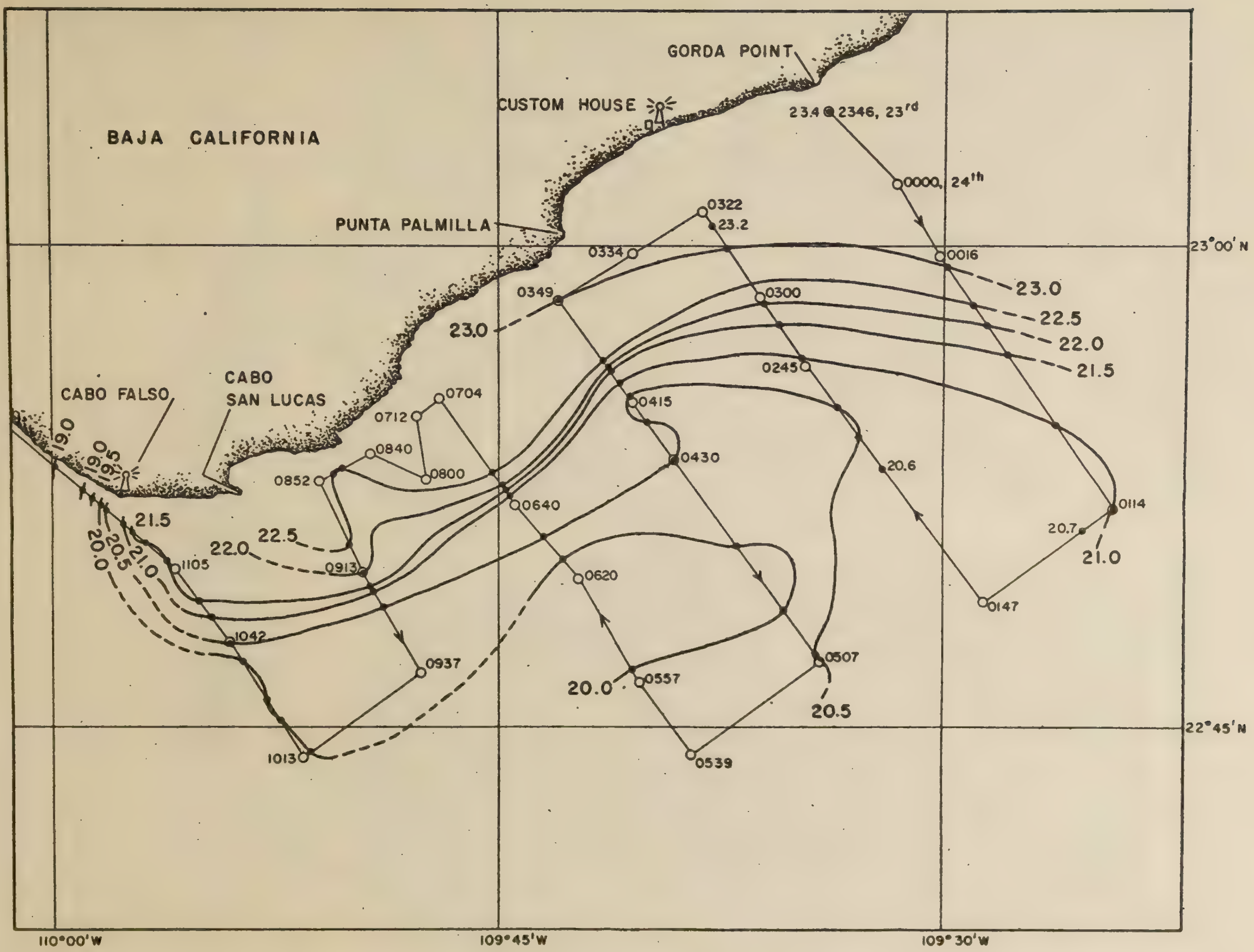

BAJA CALIFORNIA
GORDA POINT
CUSTOM HOUSE
PUNTA PALMILLA
CABO FALSO
CABO SAN LUCAS
23°00'N
22°45'N
22°30'N
110°00'W
109°45'W
109°30'W
109°15'W
0956, 19 APRIL
1235, 20 APRIL
1840
1615
1705
0107
0134
1022
1039
1534
1518
1830
1850
1050
0908
0300
0330
0400
2245
2000
1345
1250
1303
2050
2115
0530
0553
23.8
23
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18

Fig. 2 Distribution of surface isotherms (^{o}C) at front 5, off Cape San Lucas, Lower California, from the initial thermograph survey (0956 hrs 19 April to 1235 hrs 20 April 1961), the track of which is shown.
--o-- time check; --●-- temperature check.


BAJA CALIFORNIA
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0557
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0620
0640
0704
0712
0800
0840
0852
0913
0937
1013
1042
1105
23.0
22.5
22.0
21.5
20.5
19.0
19.5
23°00'N
22°45'N
110°00'W
109°45'W
109°30'W

Fig. 3 Distribution of surface isotherms (^{o}C) at front 5, off Cape San Lucas, Lower California, from the final thermograph survey (2346 hrs 23 April to 1105 hrs 24 April 1961), the track of which is shown.
--o-- time check; --●-- temperature check.

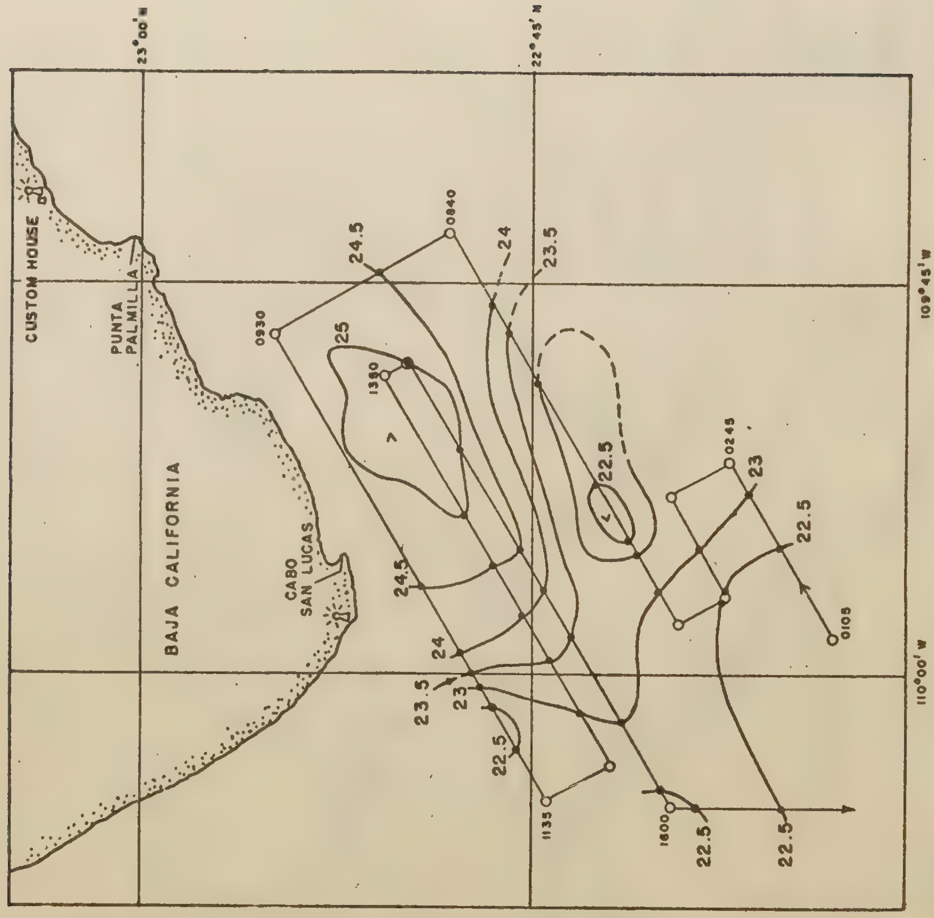
23°00'N
22°45'N
109°45'W
110°00'W
CUSTOM HOUSE
PUNTA PALMILLA
BAJA CALIFORNIA
CABO SAN LUCAS
0840
0930
1330
0245
0105
1135
1600
25
24.5
24
23.5
23
22.5

Fig. 4 Distribution of surface isotherms (°C) at front 3, off Cape San Lucas, Lower California, from a thermograph survey (0105 hrs - 1600 + hrs 22 May 1960), the track of which is shown.
--o-- time check; --●-- temperature check.

were made; a pass consisted of repeated rapid lowerings of a BT while the vessel moved slowly through the front. A bucket-thermometer reading of the surface temperature and a sample of water, for salinity determination, were taken with each BT. These passes were made about 12 mi southeast of Punta Palmilla.

Fig. 5 shows the temperature profile derived from one of the passes made at front 5. It does not differ qualitatively from those of the other two passes, but does encompass a somewhat greater range of surface temperature. The chief feature is the relatively complicated structure at depth compared with that at the surface. The warm water apparently intrudes into the cool, while the cool may intrude into the warm, complementarily (16°, 17°, 18° and 19°C isotherms). The 21°, 22° and 23°C isotherms, by which the front is detected by the thermograph, do not contribute to the large inversions at mid-depths (20 - 70 m).

A similar BT pass made at front 2 also showed a temperature structure at depth that was not revealed by observations at the surface. This deep (35 - 55 m) structure took the form of a layer of water of temperature about 20°C underlying surface water the temperature of which ranged from about 19.9°C to about 21.7°C across the front. This layer of water was interrupted in all three passes made there, being absent directly beneath the middle of the front as observed at the surface. This structure could be derived from that found at front 5, though this does not mean that the front 5 situation actually existed at front 2. Nevertheless, there is a strong indication that similar processes occur at both fronts, though presumably with different intensities.

Cromwell and Reid (1956) use the term "frontal layer" to mean the highly stratified boundary between the two kinds of water forming the front; in the fronts they reported, this layer was inclined towards the surface and became more or less horizontal at some depth above the main thermocline. Thus, the front observed on the thermograph corresponds to where the frontal layer meets the sea surface. Evidently, the Cape San Lucas frontal system has a more complicated, but perhaps less well-defined, frontal layer than those they observed. The 16°, 17° 18° and 19°C isotherms (Fig. 5) are not close together in the zone of inversion, which suggests that mixing occurs there. The stippled areas, following the presentation of Cromwell and Reid, show water that is practically isothermal vertically. In the fronts they reported on there was little salinity gradient, in which case density was almost entirely determined by temperature; hence vertical mixing would require least energy where water was vertically isothermal. This is much less true of fronts, such as the one being discussed, where salinity is important in determining density. There are five main parcels of water that are vertically isothermal: one is the surface water, another is the deep water (below the 14°C isotherm); the other three correspond to the intrusion of warm water and to the cool water above and below this warm intrusion. The main thermocline is at about 70 m depth on the cool side, and at between 30 m and 50 m depth on the warm side. There is a shallow thermocline on the cool side, formed by the 18°, 19° and 20°C isotherms which constitute the intrusion

Table I

No. of G.E.K. observation	1	2	3	4	5	6	7	8	9
Current direction (°True)	203	209	215	077	215	215	228	219	044
Current velocity (cm/sec)	11	19	3	16	11	30	22	26	4
Surface temperature at start of observation (°C) 1/	22.5 w	22.0 m	21.0 c	20.2 c	22.0 m	22.8 w	22.3 w	21.3 m	21.0 c

1/ For purposes of discussion, here and elsewhere, the surface temperature has been arbitrarily classified as warm (w) — > 22.0°C, middle (m) — 21.0° - 22.0°C, and cool (c) — < 21.0°C.

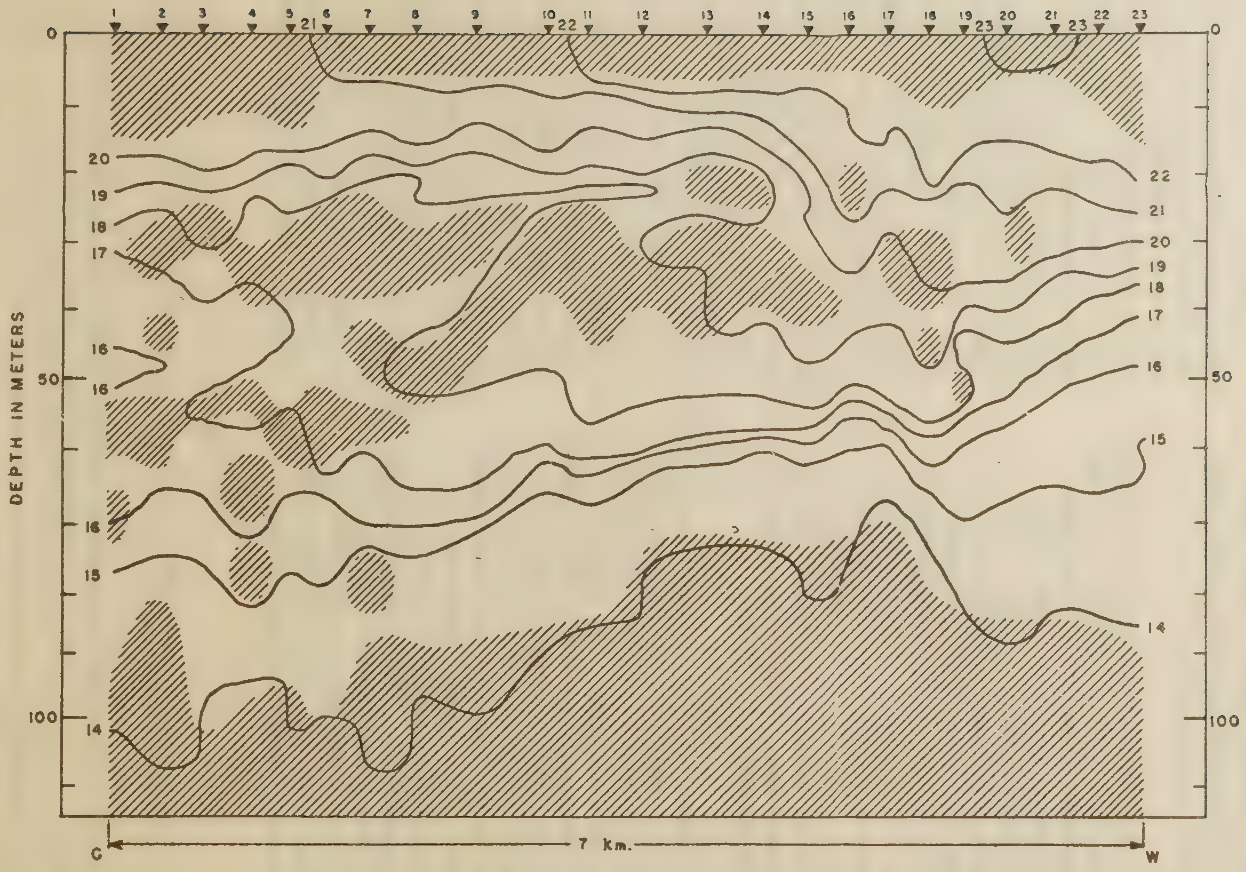

Fig. 5 The temperature profile ($^{\circ}C$) based on a BT pass (BT's Nos. 1 to 23) across front 5. Stippled areas indicate water that is practically vertically isothermal.
c - cool side; w - warm side.

of (probably) upwelled water from north of Cape Falso into the frontal area; these isotherms are shown in Fig. 2.

Fig. 6 shows the gradients of temperature (T), salinity (S), and thermosteric anomaly (δ_T) across front 5 at the surface; the temperature readings were from the bucket thermometers, and the salinity from the water samples collected with each BT on pass no. 3; δ_T was computed from these contemporaneous values of temperature and salinity. The close agreement of the temperature and salinity gradients shows that the front was formed by warm (T~23°C), saline (S≳35.00°/oo) water to the east and north, and by cool (T~20.5°C), less saline (S~34.60°/oo) water to the west and south. Comparable values for front 2 are: 19.6°C - 34.32°/oo and 21.6°C - 34.72°/oo.

The temperature inversion at front 5, so obvious in Fig. 5 and the profiles based on the BT passes, appears in the temperature profile based on data from a triplet of 10-bottle hydrocasts to about 250 m depth; Station 5B1 on the warm side, 5B2 in the middle, and 5B3 on the cool side. The casts were made two days after the BT passes. In this profile, only the 17°C isotherm was inverted. Another triplet of similar casts (station 5E1 (w), 5E2 (m), and 5E3 (c)), made a day after the first three, generated a profile lacking an inversion, though the 17°C isotherm was more than 10 m deeper at the middle station that at either lateral station. This apparent development, from the BT pass to the last triplet of hydrocasts, suggests that some mixing or redistribution of heat has taken place, but it should be noted that the three groups of observations were not all in exactly the same place, nor were they quite similarly related to the front at depth. They were all grouped in an area between latitudes 22°44' and 23° North, and longitudes 109°27' and 109°40' West. The profile based on the BT's taken for each hydrocast showed an inversion in the 17°C isotherm for the first triplet (B series) of casts, and in the 16°C isotherm for the second set (E series).

The salinity is the best indicator of the two kinds of water forming the front, judging from the salinity profiles of the two triplets of hydrocasts. All such profiles were drawn in the most objective way even though they were largely interpolated. All properties were drawn against the thermosteric anomaly first; isohalines were determined by the observations at the stations and by the intersections of specific isotherms and specific isosteres. The profiles of properties with depth were then derived from those of properties with thermosteric anomaly.

The detail imparted to the salinity profile by this method agrees strongly with the temperature structure seen on Fig. 5. Fig. 7 shows the salinity profile for the first triplet (B series) of hydrocasts. The 17°C isotherm from the corresponding temperature profile has been drawn on the salinity profile to show the close agreement between the cooler, lower salinity water and the warmer, higher salinity water. The salinity structure shown by the profile - complementary intrusions of the two kinds of water into each other - persisted almost unchanged till the later triplet (E series) of hydrocasts; the salinity profile of this later series (not given here) showed that the cooler, less saline water apparently moved farther into the warmer, more saline water, for it was observable as a pronounced salinity minimum at the "warm" station at about 30 m depth. The salinity-depth curves in Fig. 7 are based on the salinities observed and on those interpolated at standard depths. The curve for the warm side shows the marked influence of low-salinity water at about 30 m and 70 m depths; that is, above and below the prominent obtrusion of high-salinity water between 30 m and 70 m depths. The curve for the middle station shows that the two levels of salinity, characterizing the two types of water forming the front, are only mixed within a relatively narrow range of depth, because the curve is essentially like that of the cool side down to about 25 m depth and like that of the warm side from about 40 m to about 130 m where all three curves become practically the same. Above about 125 m these three curves resemble the T-S curves.

Although oxygen, nitrate-, and nitrite-nitrogen contents were measured for each cast-bottle sample, their profiles do not throw much further light on the structure of the front. The oxygen profiles qualitatively resemble the corresponding temperature profiles, except that the oxygen profile of the first (B) series of casts lacks the inversion found in the 17°C isotherm in the B series temperature profile. The nitrite profiles showed maxima: at about 25 m on the warm side in the first series of casts; at about 30 m on the warm and cool sides of the second series, with a somewhat lower value in the middle. The maximum on the warm side in the first series is a little shallower than the salinity maximum, but corresponds fairly well with the sharp salinity gradient. The nitrate profiles show maxima at greater depths than

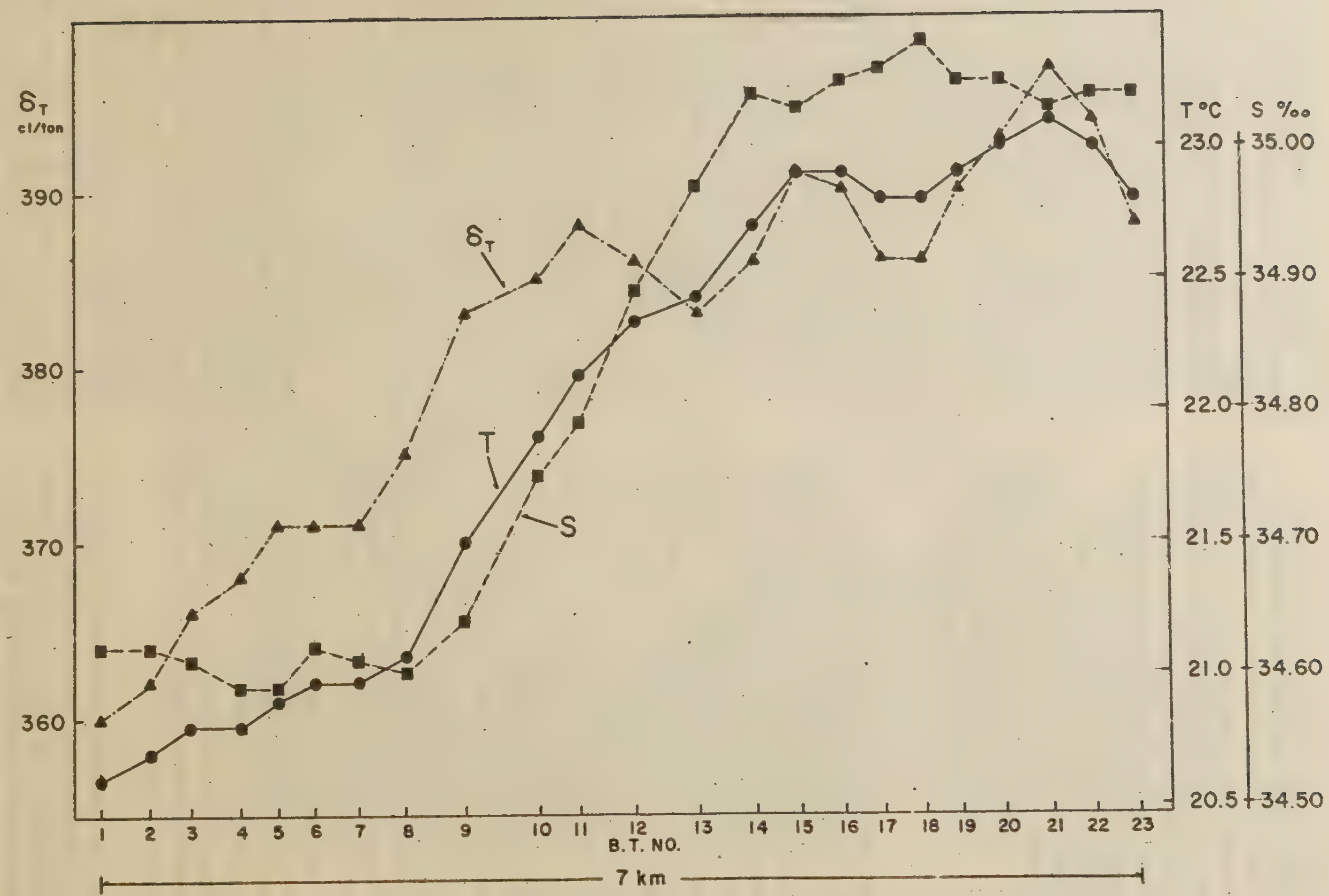

Fig. 6 Gradients of surface temperature (T), salinity (S), and thermosteric anomaly (δ_T), across front 5, from observations made with each BT lowering on BT pass no. 3 (Fig. 5).

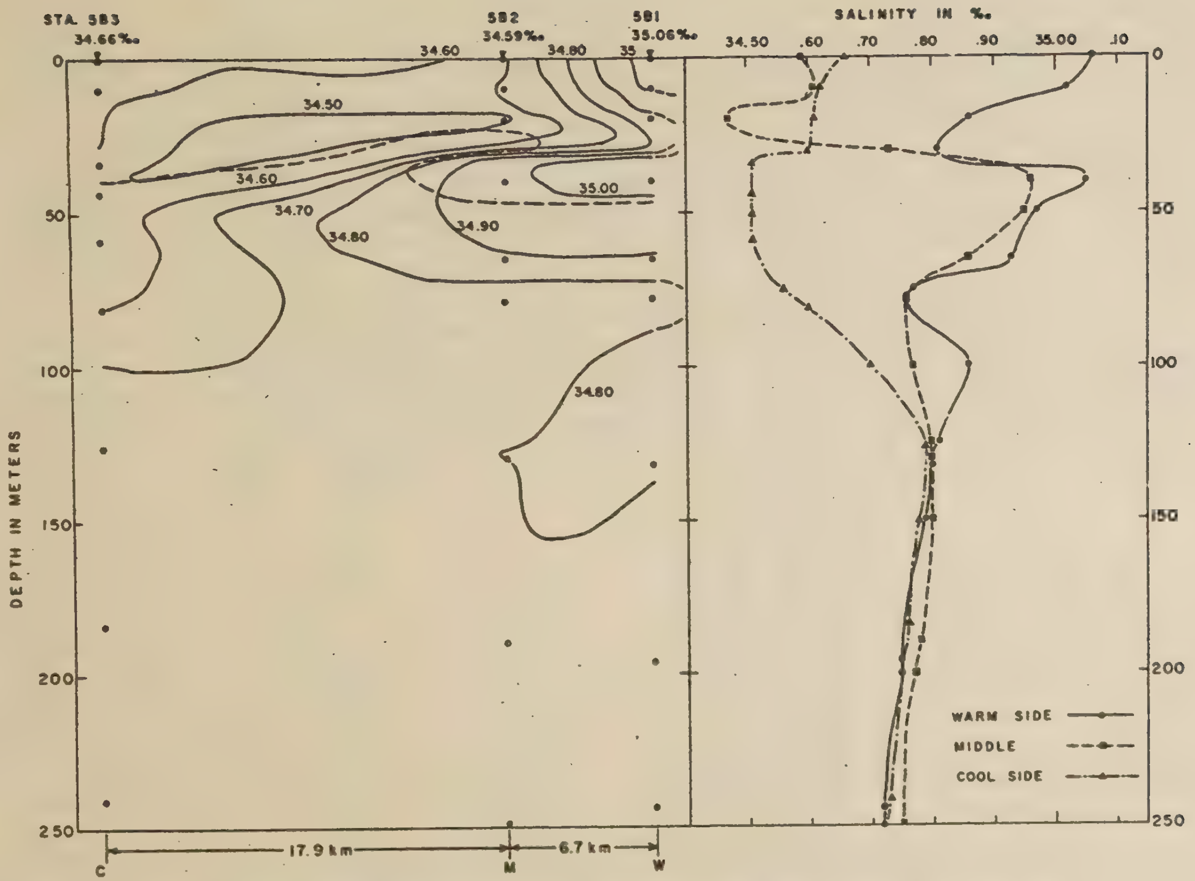

Fig. 7 The salinity profile and salinity-depth curves for the first (B) series of hydrocasts at front 5. Stations 5B1, 5B2, and 5B3 are on the warm side (w), in the middle (m), and on the cool side (c) of the front, respectively. The dotted contour is that of the 17°C. isotherm from the corresponding temperature profile, to show the relation of the temperature inversion to the salinity inversion.

those of the nitrate, as might be expected from the fact that nitrate succeeds nitrite in oxidative decay. The nitrate profiles also show other features that are not readily explained, but these are, conveniently, well below the frontal zone.

Most of the results from fronts 1, 2, and 4, besides being based on fewer and less coherent observations, do not permit any confident explanation. Apparently, Gulf water did not participate in them, unless it had been much modified. Even so, the most probable salinity structure that the data provide is not entirely different from that found at front 5. There was not, evidently, a simple interface between the warm and the cool water. The surface temperature difference across front 2 (10 May 1960) was similar to that across front 4(23 May 1960), and the actual values were similar: front 2 - 19.96° to 21.74°C: front 4 - 19.34° to 21.00°C.

This was surprising, considering that these two fronts were about two weeks apart; they were in almost the same place, however. Their respective T-S curves, for warm and cool sides, showed that a significant amount of change had taken place during the two weeks. The composition of their plankton on either side had also changed significantly.

These fronts far offshore were also moving faster than did fronts 3 and 5 (at Cape San Lucas) which made study of them difficult. For this and other reasons they will not be further considered here.

The results of biological observations at front 5 do not show any clear-cut patterns. Time did not allow us to make the density of observations so essential to obtaining significant biological results. The chief point of interest is whether this front (5) aggregates biota. Some results suggest that it does, others do not.

A triplet of Van Dorn plastic samplers was made at almost the same time as the first (B) series of hydrocasts. To avoid significant time delays, each cast consisted of only four samplers at 0, 25, 40, and 100 m depths. Therefore, the profile based on them (Fig. 8) cannot be considered quite reliable, even though it shows a marked maximum at the middle station at 25 m. A special cast to determine beam transmission and chlorophyll a at each meter of depth was made in the middle of the front at station 5E2 (second series of hydrocasts); this showed that chlorophyll a concentration changed markedly with small changes in depth. Owing to this fact, there is the possibility that maxima, such as that found in the middle of the front, existed also on either side, but that the wide-spaced bottles failed to sample these.

As it stands, the profile shows that maxima existed at all three stations, with the greatest in the middle. There the chlorophyll a concentration was approximately twice as great as that in the maxima at either station to the side. The profile maximum (0.66 mg. C per m^3) coincided with the high-salinity (S~34.90 °/oo) water (see Fig. 7).

The number of samplers per cast was minimized to ensure three things: i) that a cast, started in the middle of the front, did in fact sample "middle" water (at this time the structure of the front (5) at depth was not known because no data had been worked up); ii) that there was no marked time lag between the sampling of the warm side and of the cool side; iii) that water filters were freed of earlier samples in time for later ones.

Similar practical considerations, especially the great importance of eliminating difference in starting times of productivity experiments, confined our observations of productivity to the surface water. It usually took at least half an hour to cross the front (at 9 kt), and incubation of samples should start as close to local apparent noon as possible, because incubation should be for half a solar day for optimum results. The productivity at the surface increased on passing from the warm side to the cool; the values were: 6.87, 11.88, and 16.38 mg. C/m^2/day.

These two groups of results (chlorophyll a) indicating aggregation of phytoplankton in the front, the other (surface productivity) indicating a trend from one side to the other, characterize the remaining biological results.

Table II summarizes the results of net hauls made at front 5. All hauls were made along an isotherm (warm, middle or cool). The isotherm was noted from the thermograph and the vessel was allowed to drift; it usually drifted along an isotherm and the direction was noted (if possible) and used for the tow. The thermograph was checked during the tow to ensure that the haul did not pass into a less desirable kind of water.

To determine whether the front was a focus of biota, ratios of standardized volumes from one

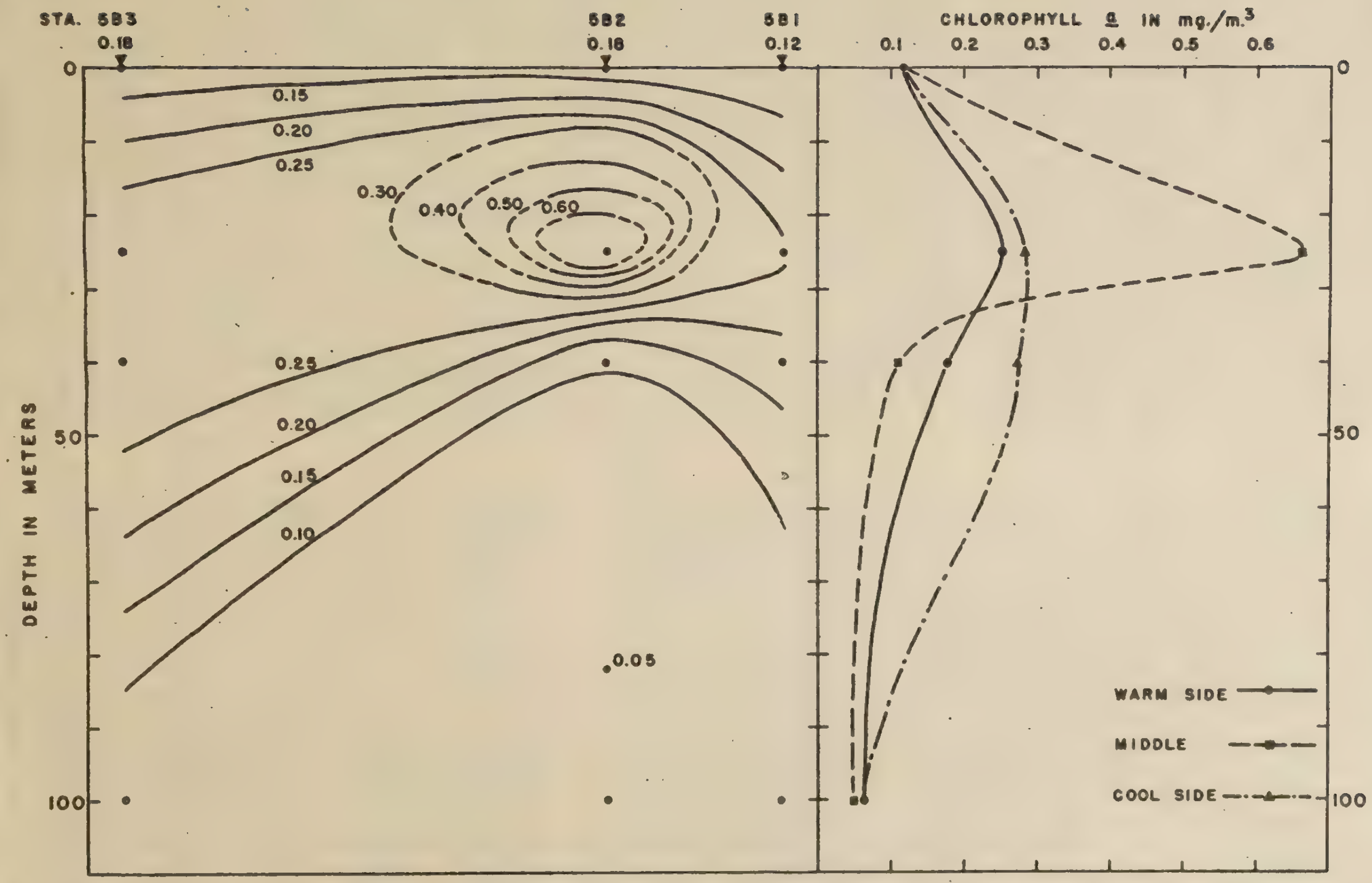

Fig. 8 The chlorophyll a profile and chlorophyll a - depth curves based on three Van Dorn plastic sampler casts at front 5. Stations 5B1, 5B2, and 5B3, correspond approximately to those on which the salinity profile (Fig. 7) was based.

haul to the next, across the front have been given (the volume for the warm side has been set at unity). It is assumed that if the front aggregates zooplankton, the volume in (the middle of) the front will be greater than that to either side. The sampling methods, which are quite standard, are open to criticism. The oblique hauls sample water below the frontal zone (depth $>$120 m). It is felt, however, that contributions from below the frontal zone are i) relatively independent of the front and not greater on one side than the other; ii) relatively small, because one set of hauls was taken at night when effects due to vertical migration would be minimal and the other was taken at dusk when these effects would be tending to a minimum (that is, the plankton would be mostly in the upper hundred meters). Most of the catch was, then, in the frontal zone and the relation of the catches to the front may indicate well enough the effect of the front on the biota. Another natural objection is that oblique hauls on either side of the front may sample parcels of water from the opposite side, by virtue of the Z-shaped interface (see Figs. 5 and 7). This is possible, but the data show that the cool side has a higher standing crop than the warm side; hence, if the haul on the warm side were sampling a significant amount of cool plankton-rich water, the observed differences would very likely be much less than they are.

From Table II we see that, according to the two sets of oblique hauls, the front aggregates zooplankton (ratios: 1.0 to 5.0 to 2.2; and 1.0 to 10.0 to 3.8). There is some suggestion that this is true of the Clarke-Bumpus samplers above the thermocline, but these nets sample so little water (about 70 m^3) that the differences are probably not reliable. These samplers were towed at three depths at a time on one wire; those below the thermocline failed in each haul.

Clarke-Bumpus samplers in the thermocline (bottom of mixed layer) show a trend of increasing volumes from the warm into the cool water.

The surface (horizontal) hauls also show increasing volumes towards the cool side, the ratios (1.0 to 3.4 to 8.7) being significant. Significance has not been tested statistically; the rough rule that differences of half or double a given value are significant, has been used. This rule, derived from studies by Winsor and Clarke (1940) and Silliman (1946), was based on counts and not volumes, but it is useful as a conservative rule-of-thumb.

Nekton-net hauls, the catch of which is largely micronekton (minimum linear dimensio of 5 cm), show increasing values on passing from the cool to the warm side. It is supposed of course, that the nekton would not be directly (mechanically) aggregated by the front, though it might accumulate there by preference; note that the micronekton components of the other ne hauls have been given in Table II. The zooplan component of the nekton hauls, mostly relativel large euphausiids (about cm long), was much greater in the middle and on the cool side of the front. This element of the biota was not apparently caught by any of the nets except this big nekton net which samples only to a depth of 115 m at the most (Blackburn and associates 196

Aliquots of each sample were sorted and th numbers of the predominant groups counted; the volumes of the most abundant of these groups w measured by the method of Yentsch and Hebard (1957). Table III shows the ratios of counts (sta dardized to the full sample and to 10^3 m^3 of wat strained), for qualitative comparison with volum ratios given in Table II. The following ratios a of particular interest: i) those showing much hig values in the middle of the front - euphausiids in both series (A and F) of oblique hauls, pteropod the first (A) series of oblique hauls (the second had a large number only on the cool side), cope and chaetognaths in the second (F) series of obl hauls and the Clarke-Bumpus hauls above the thermocline; ii) those showing much higher values on the cool side only - copepods, euphau pteropods and chaetognaths in the surface (D) se of hauls, fish and stomatopod larvae in the nek (D) hauls; iii) those showing much higher value on the warm side - red crab larvae in the Clark Bumpus hauls in the thermocline, red crab adul and prawns (shrimps?) in the nekton hauls; iv) those showing very low values in the middle chaetognaths in the Clarke-Bumpus haul in the thermocline; v) those showing high values on t cool side and in the middle - euphausiids in the nekton (D) hauls. These results will not be analyzed further in this paper. The use of indicator organisms to determine water masse awaits further study, but should prove most hel ful. Evidently, some groups are considerably more abundant than others, in relation to the fr and it is doubtful that even accidents of samplin can account for this. Nevertheless, no consis pattern is evident, and much more sampling is needed to determine with certainty whether this (convergent) front physically aggregates the pla Another difficulty, which might be diminished b

Table II

Results of net hauls made at the Cape San Lucas Front (front 5)

Station	Time of day	Depth of tow	Vol. plankton per $10^3 m^3$	Ratio of volumes	Vol. micronekton[3] per $10^3 m^3$	Ratio of volumes	Dominant forms: Zooplankton (by vol.&/or number)	Dominant forms: Micronekton[3]
OBLIQUE 1m NET HAULS								
5A1 (w)[1]	n[2]	300	20	1	95	1	copepods, chaetognaths, ostracods	red crabs
5A2 (m)[1]	n	261	101	5.0	3	0.03	copepods, euphausiids, pteropods	
5A3 (c)[1]	n	329	43	2.2	158	1.7	copepods, pteropods, euphausiids, ostracods	red crabs
5F1 (w)	d[2]	200	20	1	120	1	copepods, chaetognaths	red crabs
5F2 (m)	d	170	199	10.0	1638	13.7	euphausiids, copepods	red crabs
5F3 (c)	d	321	75	3.8	12	0.1	copepods, chaetognaths, pteropods, siphonophores	red crabs
HORIZONTAL 1m NET HAULS								
5D2 (w)	n	3	52	1	46	1	copepods, chaetognaths, pteropods	a large salp
5D3 (m)	n	3	179	3.4	0	-	chaetognaths, copepods, pteropods, siphonophores	
5D1 (c)	n	3	452	8.7	52	1.1	copepods, pteropods, siphonophores	salps
HORIZONTAL CLARKE-BUMPUS NET HAULS								
i) ABOVE the thermocline								
5C1 (w)	d	15	7	1	0	-	copepods, chaetognaths, pteropods	
5C2 (m)	d	20	78	11.1	0	-	chaetognaths, copepods	
5C3 (c)	d	15	58	8.3	0	-	euphausiids, copepods, siphonophores	
ii) IN the thermocline								
5C1 (w)	d	40	59	1	0	-	red crab larvae, chaetognaths, copepods	
5C2 (m)	d	35	63	1.1	0	-	euphausiids, red crab larvae, copepods	
5C3 (c)	d	25	127	2.2	0	-	euphausiids, copepods, chaetognaths	
OBLIQUE 5ft x 5ft NEKTON NET HAULS								
5D2 (w)	n	100	0.1	1	66	1		red crabs, fish, prawns
5D3 (m)	n	100	5	50	9	0.14	euphausiids	red crabs, fish
5D1 (c)	n	100	5	50	8	0.12	euphausiids, stomatopod larvae	fish

[1] See Table I.

[2] n = night; d = dusk.

[3] Micronekton is, roughly speaking, a small organism of minimum linear dimension 5 cm. and of maximum linear dimension of, say, 15 cm.

Table III

Ratios of major groups of organisms in the net hauls made on the warm side, in the middle, and on the cool side of the Cape San Lucas Front (front 5). The ratios are of the counts, and the count of the warm side is set at unity. Ratios are only given when a group was represented in all catches of a triplet.

OBLIQUE HAULS.

Organisms Sta.	5A1 (w)	5A2 (m)	5A3 (c)	Sta. 5F1 (w)	5F2 (m)	5F3 (c)
Copepods	1.0	1.7	0.8	1.0	5.6	2.2
Euphausiids	1.0	7.9	4.0	1.0	11.0	2.5
Pteropods	1.0	24.7	11.6	-	-	-
Ostracods	1.0	1.2	0.9	-	-	-
Chaetognaths	1.0	0.5	0.4	1.0	4.5	2.6
Average	1.0	2.3	1.2	1.0	7.2	2.4
Total plankton volumes	1.0	5.0	2.2	1.0	10.0	3.8

HORIZONTAL HAULS

i) SURFACE

Organisms Sta.	5D2 (w)	5D3 (m)	5D1 (c)
Copepods	1.0	1.4	6.1
Euphausiids	1.0	2.1	5.2
Pteropods	1.0	3.2	27.0
Chaetognaths	1.0	1.8	1.6
Siphonophores	1.0	2.1	4.9
Average	1.0	2.1	9.0
Total plankton volumes	1.0	3.4	8.7

ii) CLARKE-BUMPUS: a) ABOVE thermocline

Organisms Sta.	5C1 (w)	5C2 (m)	5C3 (c)
Copepods	1.0	6.0	1.2
Euphausiids	-	-	-
Pteropods	-	-	-
Chaetognaths	1.4	14.0	1.1
Siphonophores	-	-	-
Average	1.0	10.0	1.1
Total plankton volumes	1.0	11.1	8.3

b) IN thermocline

	5C1 (w)	5C2 (m)	5C3 (c)
Copepods	1.0	0.8	1.8
Red crab larvae	1.0	0.5	~0
Chaetognaths	1.0	0.1	0.8
Average	1.0	0.5	0.9
Total plankton volumes	1.0	1.1	2.2

OBLIQUE HAULS

NEKTON

Sta.	5D2 (w)	5D3 (m)	5D1 (c)	
Red crab adults	1.0	0.04	~0	
Prawns	1.0	0.08	-	
Fish	1.0	0.3	4.0	
Leptocephalus	1.0	1.2	1.8	
Squid	1.0	3.0	2.7	
Euphausiids	1.0	73.2	64.8	} plankton
Stomatopod larvae	1.0	0.8	11.3	} plankton
Average	1.0	11.2	12.1	
Total volumes	1.0	0.2	0.2	

further close inspection of the data to hand, is that of grazing; the rate may well be different in the middle from what it is on either side, and could affect the results of net hauls significantly. My tentative view, however, is that aggregation here is more likely to occur than not, but may well be masked to some extent by the relatively greater contribution of cool-water biota at this time (spring, the upwelling season) of the year. The standing crop of zooplankton at front 2 was about three times greater on the cool side than on the warm; the values were roughly the same on either side of front 4, however.

Front 5, as noted earlier, was not visible on the sea surface, and although the sea state changed from calm to choppy as the vessel moved offshore from the lee of the land mass, this fairly rapid change was not related, directly at least, to the front. The front was therefore in calm waters, and, in these, marlin were especially abundant. A few small sport-fishing boats had successful fishing while we were there. Birds were not particularly abundant.

No tuna or tuna-fishing vessels were sighted during the work at front 5 (19-24 April, 1961); a few schools of tuna (species unindentified) were sighted near the Tres Marias Islands on cruise TO-60-1 (May 1960), but no tuna-boats were seen. Fig. 9 and 10 show the distribution of catch (of yellowfin) and effort by purse-seiners in and near the Gulf entrance in May 1960 and April 1961, respectively, corresponding to the months of the cruises TO-60-1 and TO-61-1. The data were kindly supplied by the Inter-American Tropical Tuna Commission. No conclusions are drawn from these two Figures at present, but a comparison of Figures 1 and 9 is of interest.

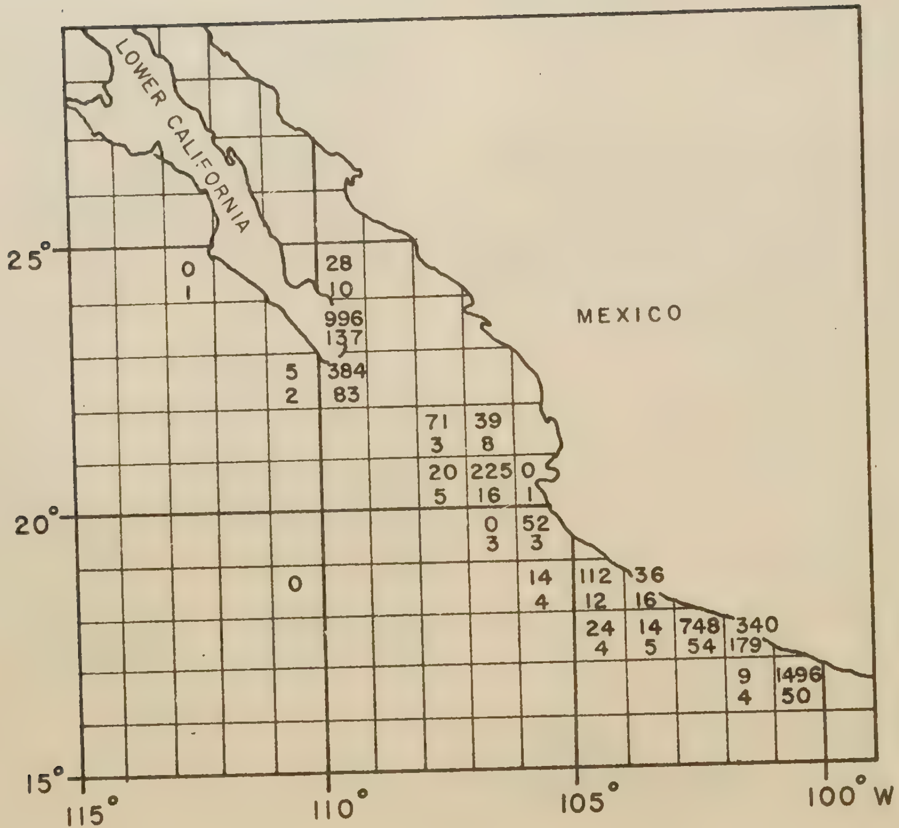
LOWER CALIFORNIA
MEXICO
25°
20°
15°
115°
110°
105°
100° W
0
1
28
10
996
137
5
2
384
83
71
3
39
8
20
5
225
16
0
1
0
3
52
3
0
14
4
112
12
36
16
24
4
14
5
748
54
340
179
9
4
1496
50

Fig. 9 Distribution of effort by purse-seiners and their catch of yellowfin, in May 1960, by one-degree squares, off western Mexico and Lower California. The upper figure in each square is the catch in tons, the lower figure is the corresponding effort in standardized boat-days.

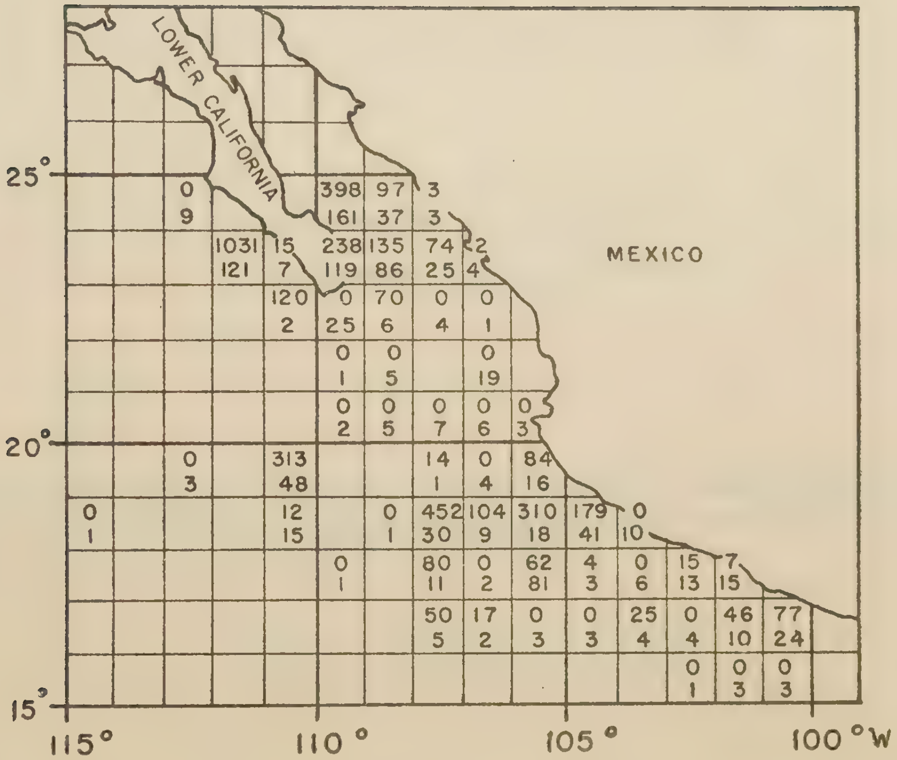
LOWER CALIFORNIA
MEXICO
25°
20°
15°
115°
110°
105°
100°W
0 9
398 161
97 37
3 3
1031 121
15 7
238 119
135 86
74 25
2 4
120 2
0 25
70 6
0 4
0 1
0 1
0 5
0 19
0 2
0 5
0 7
0 6
0 3
0 3
313 48
14 1
0 4
84 16
0 1
12 15
0 1
452 30
104 9
310 18
179 41
0 10
0 1
80 11
0 2
62 81
4 3
0 6
15 13
7 15
50 5
17 2
0 3
0 3
25 4
0 4
46 10
77 24
0 1
0 3
0 3

Fig. 10 Distribution of effort by purse-seiners and their catch of yellowfin, in April 1961, by one-degree squares, off western Mexico and Lower California. Upper figure in each square is the catch in tons, the lower figure is the corresponding effort in standardized boat-days.

Experience Paper No. 35

LA PESQUERIA DEL BONITO EN EL PERU

Por

FELIPE ANCIETA

Ministerio de Agricultura
Lima, Perú

Extracto

Describe los métodos, caladeros y épocas de pesca y analiza los factores biológicos que regulan la disponibilidad de *Sarda chilensis* en aguas peruanas. Se da la producción total y por zonas y la composición de la captura.

THE BONITO FISHERIES IN PERU

Abstract

Describes fishing methods, fishing grounds and seasons, and analyzes the biological factors which regulate the availability of *Sarda chilensis* in Peruvian waters. Total and areal production are described as well as the catch composition.

LA PECHE AU PELAMIDE AU PEROU

Résumé

Décrit les méthodes de pêche, les lieux et saisons de pêche, et analyse les facteurs biologiques qui règlent la présence de *Sarda chilensis* dans les eaux péruviennes. La production totale et par zones est décrite ainsi que la composition des captures.

1 INTRODUCCION

El bonito (Sarda chilensis C y V) es la especie que ocupa actualmente el segundo lugar en importancia económica en las pesquerías peruanas. Su pesca en escala industrial es un hecho comparativamente reciente y constituyó una actividad de orden secundario hasta la Segunda Guerra Mundial, en que la UNRRA acudió en demanda de apreciables cantidades de pescado en salmuera. Al término de la guerra, la industria de envasado reemplazó a la de salazón, con gran éxito en el mercado extranjero, circunstancia que, unida a una creciente demanda de bonito para su consumo en fresco, estimuló su pesca hasta constituir ésta cerca del 50% del desembarque total.

Así, pues, aparece el bonito como la especie pionera en el desarrollo de la gran industria pesquera actual del Perú y constituye el pescado de mayor consumo para la alimentación en el mercado interno, que absorbe algo más del 40% de la producción total, a la vez que es la base de la industria conservera.

No obstante que la pesca del bonito, en términos generales, ha ido creciendo desde su inicio, el meteórico desenvolvimiento de la pesca de la anchoveta, iniciada comercialmente en 1953, relegó el bonito a un segundo plano, y en 1960, el desembarque de esa especie subió a la cifra de 3.310.000 toneladas métricas, que representa el 91,5% de la producción pesquera total en la costa del Perú, mientras que al bonito en el mismo año sólo le correspondió el 2,7%.

Una serie de factores técnicos han contribuido con los de tipo económico al desarrollo de la pesquería del bonito. La flota bonitera ha aumentado considerablemente en cantidad y capacidad de bodegas; se ha generalizado la motorización de las embarcaciones, lo que les permite cubrir un mayor radio de acción; el material sintético ha reemplazado en su mayor parte a las redes de algodón; desde 1947 se introdujo la red de cerco denominada "boliche", que tiende a generalizarse.

A no ser que la anchoveta sea impuesta como artículo para el consumo humano, existe duda de que el bonito sea reemplazado por otra especie como elemento preponderante en la nutrición del pueblo de la costa del Perú.

Los datos estadísticos de desembarque utilizados en el presente trabajo se han tomado de Iparraguirre (1959, 1961a, 1961b) y de registros inéditos del Departamento de Economía y Estadística del Servicio de Pesquería.

2 EQUIPOS DE PESCA

2.1 Métodos de pesca

En la costa del Perú, el bonito es capturado mediante el empleo de curricanes, redes agalleras a la deriva y los boliches.

Los curricanes, con los que se efectúa la pesca llamada "a la carrera", se usan principalmente en la costa norte, entre Talara y Salaverry, y en la zona de Pisco, en la costa central. Cada embarcación, motorizada o a vela, lleva comúnmente ocho líneas, dos en la popa, una a cada lado de la parte posterior de las bordas y dos sujetas a cada una de las dos varas, en la parte media de la embarcación. Algunas veces se ceba el anzuelo con carnada fresca, por lo común trozos de caballa (Pneumatophorus peruanus) o jibia (Ommastrephes gigas), pero más usual es el empleo de señuelos o "muestras", que consisten en un pedazo de hueso de cabra adosado al anzuelo al cual se atan tiras de tela roja o blanca. La pesca con este método da mejores resultados en el otoño.

Las redes agalleras son de dos tipos: boniteras y chauchilleras. Las boniteras se usan para atrapar al bonito de talla grande (60 cm. en longitud promedio). Normalmente, un paño de esta red tiene 45 brazas de largo y 5 brazas de alto, con malla estirada de 5 pulgadas. Las embarcaciones llevan de 5 a 8 paños, que se unen en el momento de tenderse en línea, quedando un extremo sujeto a una boya y el opuesto se asegura a la embarcación con un cabo.

Las chauchilleras son empleadas en la captura del bonito pequeño, llamado "chauchilla" (30 cm. de longitud promedio); su construcción y forma de pesca es similar a la bonitera, pero sus dimensiones son menores. Un paño chauchillero mide 45 brazas de largo y de 3,5 a 4 brazas de altura, con malla de 3 a 3,25 pulgadas. Cada embarcación lleva 3 paños.

El bonito mediano, llamado "cerrajón" (40 cm. de longitud promedio), amalla indistintamente en ambas redes, quedando atrapado generalmente por detrás de las agallas en las redes boniteras, o por la cabeza, en las chauchilleras.

Las fibras sintéticas están reemplazando rápidamente al hilo de algodón en la construcción de las redes agalleras.

La pesca se realiza de noche y los cardúmenes se localizan por la fosforescencia que producen los peces al desplazarse.

El boliche es una red de cerco de jareta. La longitud de los boliches varía entre 160 y 220 brazas de largo por 20 a 28 de altura, con malla pareja de 4 pulgadas. Todas estas redes son hechas de fibra sintética.

Para encerrar el bonito con el boliche es necesario que el cardumen se encuentre en grupo compacto, formando lo que los pescadores llaman "bolo", comportamiento que adquieren estos peces cuando acorralan a la anchoveta para comer.

Las embarcaciones grandes llevan, por lo general, un bote que dejan con un extremo de la red a unos 30 metros del bolo, procediendo luego al cercado hasta llegar nuevamente al bote; las embarcaciones pequeñas botan el extremo del boliche unido a una boya. Una vez efectuado el cerco, se recupera la jareta para cerrar el fondo y luego se procede a recobrar la red para concentrar a los peces en la superficie, al pie de la borda, utilizando la "pluma". Los peces son recogidos y puestos en la bodega con una red de bolsa que se abre por la parte inferior, la que se suspende de un cabo que corre por una polea.

La pesca con boliche se efectúa mayormente durante el día y los cardúmenes son ubicados por el movimiento que producen en la superficie y por las aves guaneras, que compiten el alimento del bonito. De noche se reconoce el "bolo" por la fosforescencia del mar. Unas pocas embarcaciones poseen ecosondas.

2.2 Embarcaciones

No existen tipos de embarcaciones para la pesca exclusiva de bonito, antes más bien una variedad de ellos en cuanto a forma y tamaño efectúan esta pesca.

En la costa norte, entre Talara y Salaverry, se emplea comúnmente el bote de tipo "San José-Sechura", que tiene de 22 a 28 pies de eslora, 10 pies de manga y 4 a 6 pies de puntal. Son totalmente descubiertas o con la proa cubierta, popa cuadrada y quilla corta; su capacidad es de 3 a 7 toneladas. La propulsión a vela y remos está siendo reemplazada por motores de centro. Pescan "a la carrera" y con redes agalleras. La tripulación es de 4 a 6 hombres.

La "falúa" o "buceta" (Fig. 1) es la típica embarcación bonitera de red agallera que se usa en el Callao y otros lugares de la costa central. El tamaño más común es de unos 18 pies de eslora, 6 pies de manga y 3 pies de puntal. Tanto la popa como la proa son terminados en punta, la quilla es muy pequeña y el fondo redondeado. Por lo común están totalmente cubiertas, con una escotilla casi central de unos 9 pies de largo y 3 pies de ancho, que da acceso al motor; en popa, otra escotilla más pequeña lleva a la bodega. Todas estas embarcaciones están actualmente motorizadas. La tripulación consta generalmente de 3 hombres.

Las bolicheras (Fig. 2) deben su nombre a que usan la red boliche. En 1961 operaron más de 860 bolicheras en el litoral peruano (Vásquez, 1962), de las cuales un 95% se dedicaron especialmente a la pesca de anchoveta, capturando ocasionalmente bonito. Unas 45 bolicheras pescan exclusivamente el bonito.

La capacidad de bodega de las bolicheras fluctúa entre 20 y 160 toneladas; algunas de las más grandes tienen casco de hierro. Un creciente número de ellas cuenta con equipo de radio y ecosonda.

El tipo común de bolichera dedicada a la pesca de bonito, es una embarcación de casco de madera, de unos 45 pies de eslora, 12 pies de manga y 6 pies de puntal, con capacidad de bodega de 25 a 30 toneladas. Estas embarcaciones cargan generalmente un boliche de 200 x 28 brazas y llevan 11 hombres de tripulación.

3 AREAS DE PESCA

3.1 Distribución geográfica general

El bonito *Sarda chilensis* es un escómbrido pelágico del Pacífico oriental, que vive en la Corriente de California, desde Vancouver (Canadá) a Bahía Magdalena (Baja California), y en la Corriente del Perú, desde Máncora (Perú) a Talcahuano (Chile).

3.2 Abundancia

Existe gran variación en cuanto a la abundancia de esta especie dentro de su área de distribución. Así, para el Pacífico Norte, Roedel (1953) ha señalado una mayor abundancia entre

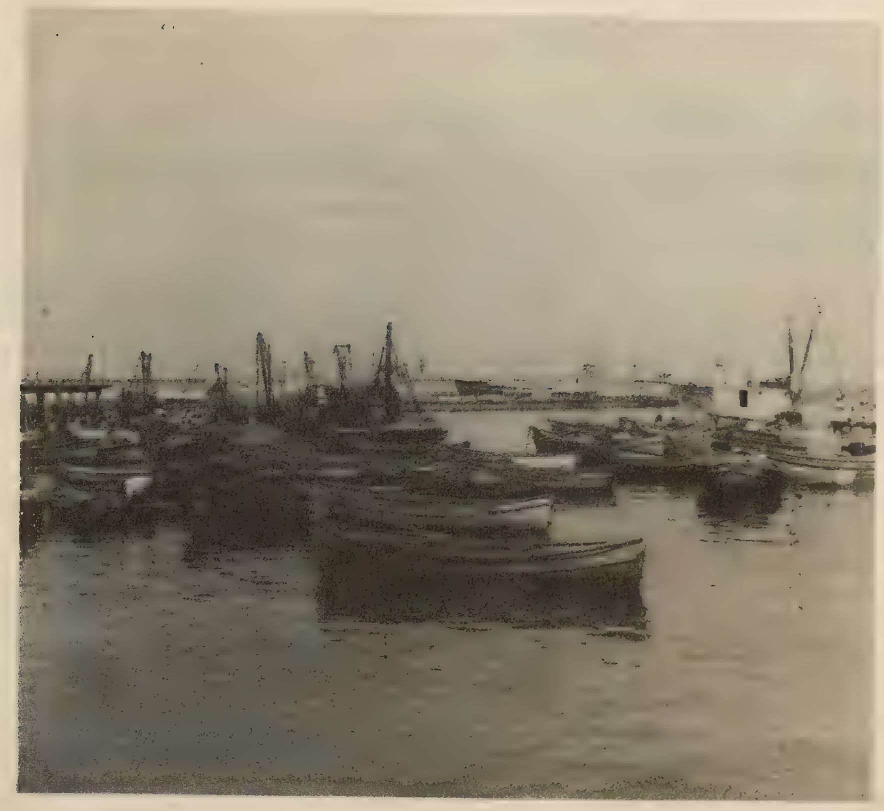

Fig. 1 Embarcaciones tipo "buceta" o "falúa" en el Muelle de Pescadores del Callao

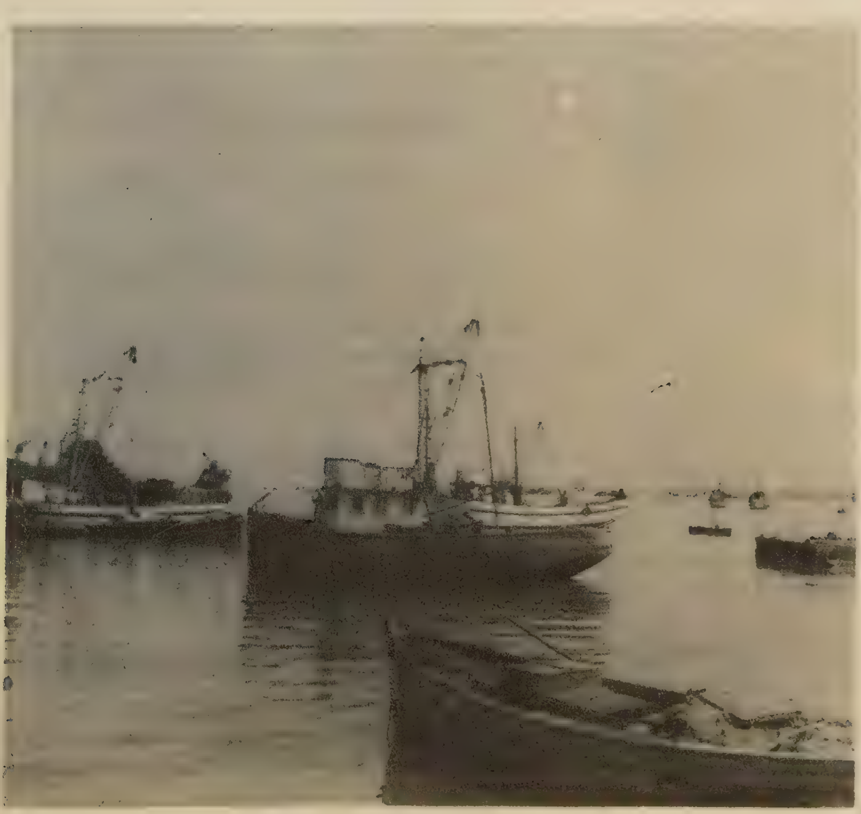

Fig. 2 Bolicheras en el Puerto del Callao

Punta Concepción y Bahía Magdalena. En el Perú, el 82,2% de la pesca, en promedio, corresponde a la zona comprendida entre Chimbote y Pisco, y en Chile, según Howard y Godfrey (1951), el centro de mayor abundancia está entre Arica y Antofagasta.

Hay que anotar que, por lo menos en el caso del Perú, donde no se dispone de datos sobre el esfuerzo de pesca, el volumen de las capturas no refleja necesariamente la abundancia relativa en las diferentes áreas. Se admite que entre Máncora y Salaverry, donde existen 18 lugares de desembarque de bonito, esta especie, con una producción promedia de 6% del total, es escasa. En cambio, la zona comprendida entre San Juan e Ilo, que produce en promedio 11,8%, cuenta con sólo 5 lugares de desembarque y, finalmente, en la zona central, Chimbote a Pisco, que produce en promedio 82,2%, existen 22 lugares de desembarque y comprende los dos centros mayores de concentración de la flota, Chimbote y Callao. Es muy probable que si el esfuerzo de pesca aumenta al sur de Pisco, la producción en esa zona se incremente en forma significativa.

3.3 Ubicación de la pesca

En el Perú, el bonito adulto se captura normalmente entre 10 y 30 millas de la costa a lo largo del litoral. Las formas menores, como el "cerrajón" y la "chauchilla", se presentan por lo general entre las 2 y 10 millas y algunas veces son atrapadas en los chinchorros (redes de arrastre de playa). De Vildoso (1955) señala que en Punta Lomas se acerca tanto a la playa que es posible cogerlo con anzuelo desde el muelle, hecho que también ha sido constatado por el autor.

4 ESTACIONES DE PESCA

4.1 Distribución estacional de las capturas

La pesca del bonito se efectúa durante todo el año; sin embargo, el volumen de las capturas varía considerablemente. El Cuadro I y la Fig. 3 indican estas variaciones, según el promedio mensual de las capturas efectuadas entre 1951 y 1959. Como se puede apreciar, la pesca disminuye sensiblemente a partir del mes de abril, descendiendo a menos de 2.000 toneladas métricas en el mes de julio, para subir progresivamente desde agosto; la temporada de pesca se considera de octubre a marzo, con su ápice en enero.

Esta curva está grandemente influenciada por las capturas de las redes agalleras, para las que la disponibilidad del bonito es mucho mayor en los meses llamados de temporada; sin embargo, a medida que aumenta el uso de los boliches para esta clase de pesca, como viene sucediendo en los últimos años, las diferencias en la distribución estacional de las capturas tienden a atenuarse, lo que puede apreciarse en el Cuadro I, situación que se hace más pronunciada en los datos incompletos de años posteriores a 1959, que hemos examinado.

4.2 Factores biológicos que acompañan a los cambios de disponibilidad

La disponibilidad del bonito aumenta en relación directa con la actividad gonadal. En efecto, de Vildoso (1960) ha realizado un estudio de la reproducción del bonito en la costa del Perú, en cuyas conclusiones se establece que el período de reproducción en forma general corresponde a los meses de primavera y verano, y durante el otoño y el invierno las gónadas están en proceso de reabsorción y recuperación; las curvas de las fluctuaciones mensuales del valor promedio del índice de madurez y del valor promedio de los óvulos, concuerdan con la curva de distribución mensual de la pesca (Fig. 3). Aclara igualmente esta autora que en el mismo momento del desove los bonitos son poco disponibles para la pesquería.

5 PRODUCCION

5.1 Desembarques totales

El Cuadro II indica las cifras de desembarque de bonito en todo el litoral peruano entre los años 1941 y 1961, así como el incremento de la producción de cada año con respecto al anterior. La gráfica de la Fig. 4 está construida con los valores de la segunda columna de dicho Cuadro.

Como se aprecia, la curva tiene una tendencia marcadamente ascendente, existiendo una diferencia de algo más de 102.000 toneladas métricas entre la producción de 1941 y la de 1961.

5.2 Producción por zonas

Para los fines de la estadística de la producción, se suele dividir arbitrariamente la costa peruana en tres zonas: zona norte (Tumbes a Salaverry), zona centro (Chimbote a Pisco) y zona sur (San Juan a Ilo). Hidrológicamente, la zona norte, en especial al norte de Paita, es menos estable que las otras dos, estando influenciada anualmente en el verano por el

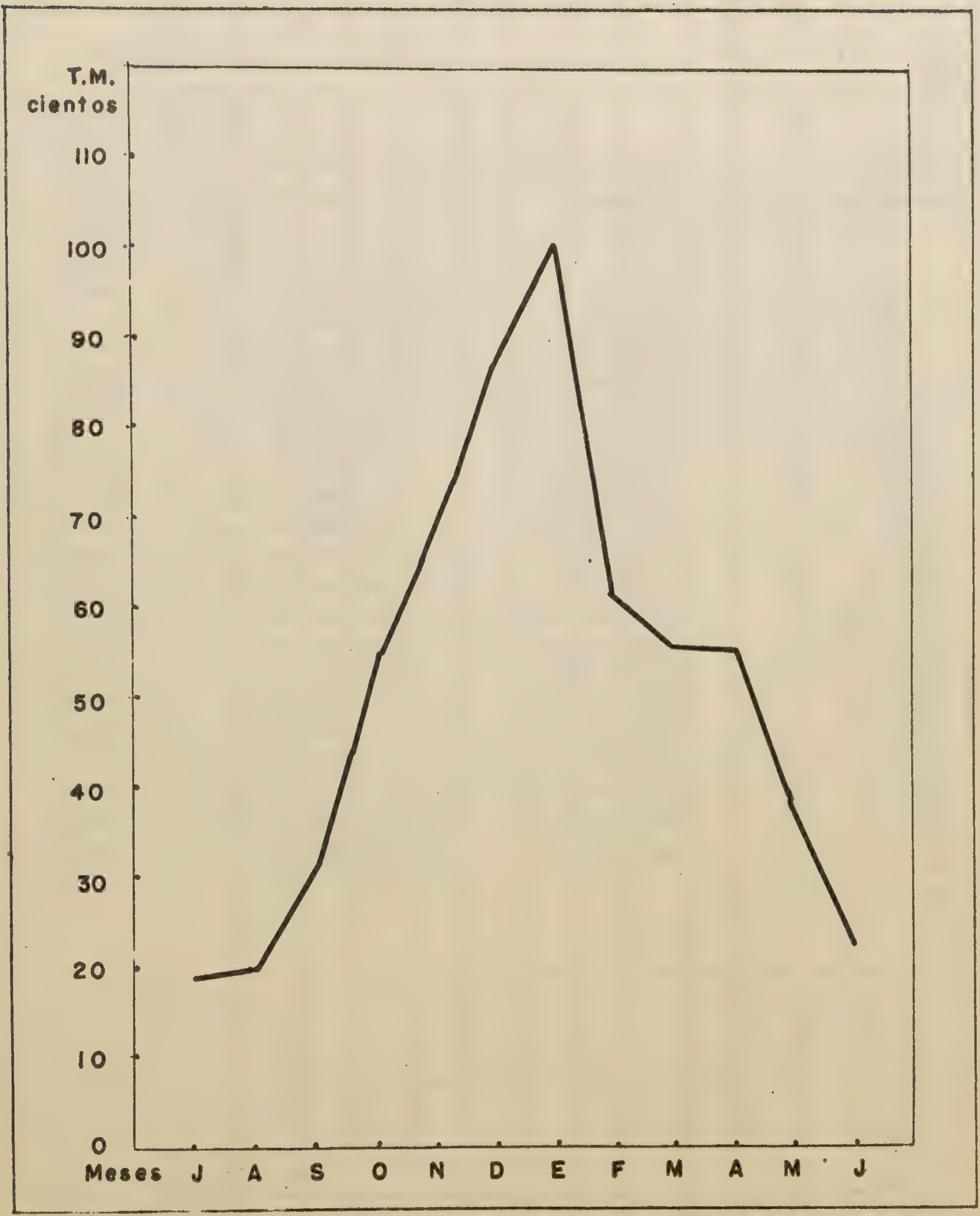

Fig. 3 Gráfica del promedio mensual de desembarque de bonito en todo el litoral desde 1951 a 1959

Cuadro I

Cifras de desembarque mensual de bonito en todo el litoral desde 1951 a 1959, en kilogramos

AÑO	ENERO	FEBRERO	MARZO	ABRIL	MAYO	JUNIO	JULIO	AGOSTO	SETIEMBRE	OCTUBRE	NOVIEMBRE	DICIEMBRE	TOTALES
1951	8'537,194	7'470,745	6'477,946	3'234,175	756,380	780,983	485,670	1'154,282	1'816,862	4'075,188	8'021,166	7'958,026	50'768,617
1952	7'969,248	7'008,109	9'810,545	4'957,666	3'523,002	951,622	952,487	739,659	3'641,005	3'267,576	4'240,446	3'428,305	50'129,670
1953	12'940,228	5'060,605	2'713,776	1'746,330	1'349,770	1'530,105	805,843	753,958	1'882,114	3'974,307	5'542,599	5'395,420	43'695,055
1954	6'180,170	5'302,619	4'709,834	3'701,018	2'902,076	2'799,416	1'078,285	1'254,493	2'495,655	5'533,217	6'025,469	10'337,563	52'319,815
1955	13'116,222	7'338,220	7'533,067	6'210,277	4'677,801	2'554,086	826,082	856,478	2'048,684	4'069,260	8'067,635	13'893,401	71'191,213
1956	13'400,494	8'036,078	5'101,726	3'850,786	4'546,383	1'842,472	1'525,596	3'093,917	4'680,559	7'374,373	14'057,861	15'916,707	83'426,949
1957	10'012,359	6'253,440	3'851,228	10'055,956	3'290,923	2'395,783	2'011,624	2'873,457	3'501,066	5'497,255	3'286,062	4'695,905	57'725,058
1958	6'602,085	2'533,281	3'512,517	7'730,367	4'202,505	1'726,996	4'572,030	2'530,311	8'373,312	9'870,860	5'761,606	8'342,407	65'758,277
1959	12'830,301	7'537,159	6'486,839	8'163,078	6'682,719	5'159,850	4'744,808	5'584,058	4'477,014	4'927,097	6'506,381	8'719,180	81'818,477
TOTAL	91'588,301	56'540,256	50'197,478	49'289,653	31'931,559	19'741,313	17'002,418	18'840,613	32'916,271	48'589,133	61'509,225	78'686,911	456'833,132
PROMEDIO	10'176,477	6'282,250	5'577,497	5'476,628	3'547,951	2'193,479	1'889,157	2'093,401	3'657,363	5'398,792	6'834,358	8'742,990	51,870,343
%	16.4	10.2	9.0	8.9	5.7	3.7	3.1	3.4	6.0	8.7	11.0	14.1	

Cuadro II

Desembarque de bonito en la costa del Perú - Años 1941 - 1961

Años	Desembarque Kgs.	Incremento anual	Porcentaje de incremento
1941	1.610.576		
1942	5.718.142	4.107.566	255,0
1943	11.966.975	6.248.833	109,3
1944	16.326.763	4.359.788	36,4
1945	18.711.001	2.384.238	14,6
1946	26.376.788	7.665.787	40,9
1947	20.144.738	(-6.232.050)	(-23,6)
1948	28.165.726	8.020.988	39,8
1949	37.963.397	9.597.671	34,1
1950	38.388.550	452.153	1,2
1951	50.768.617	12.380.067	32,2
1952	50.129.670	(-638.947)	(-1,3)
1953	43.695.055	(-6.434.615)	(-12,8)
1954	52.319.815	8.624.760	19,7
1955	71.191.213	18.871.398	36,0
1956	83.426.949	12.235.736	17,2
1957	57.725.058	(-25.701.891)	(-30,8)
1958	65.758.277	8.033.219	13,9
1959	81.818.477	16.060.200	24,4
1960	96.296.876	14.478.399	17,7
1961	104.000.000	7.703.124	8,0

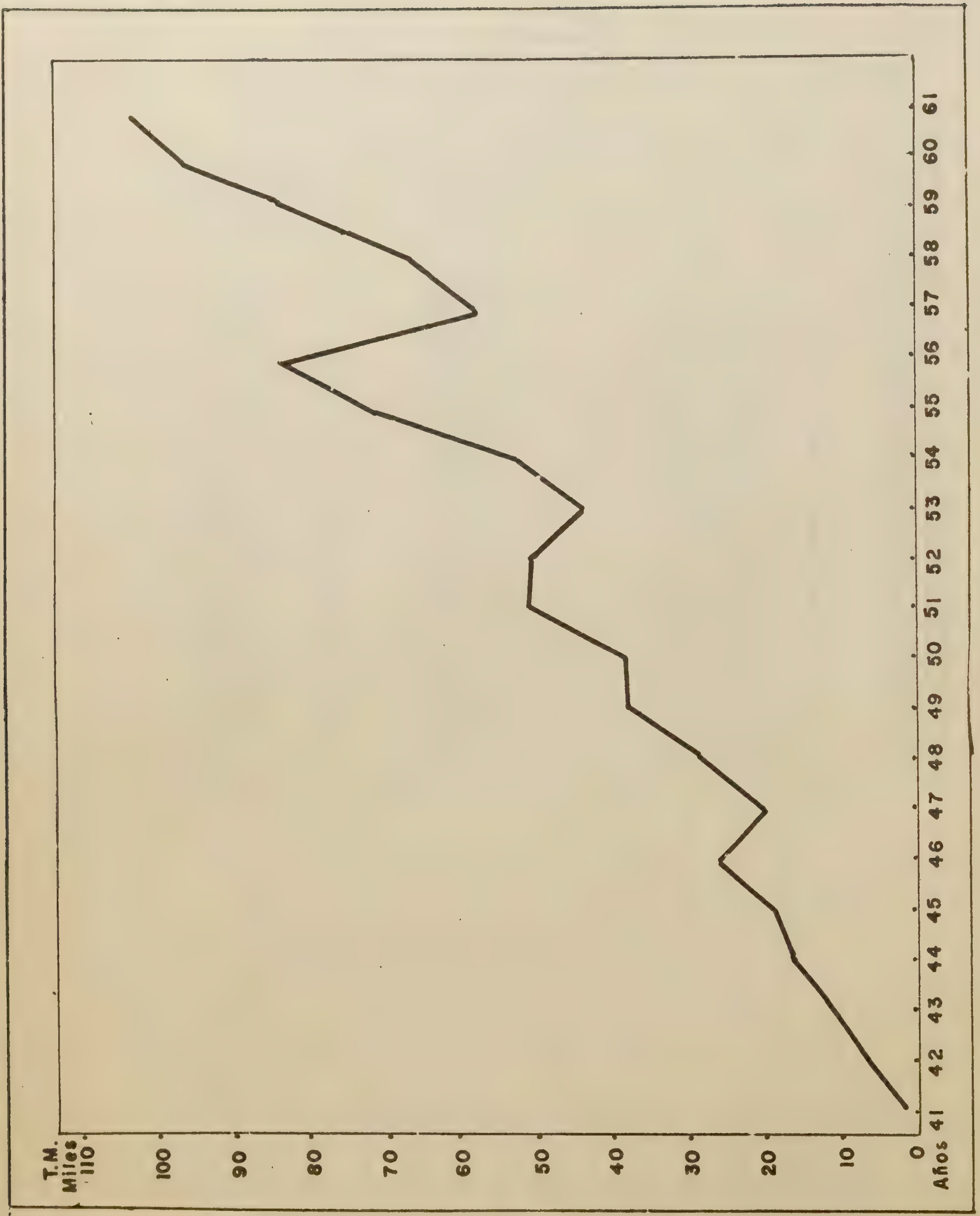

Fig. 4 Gráfica del desembarque de bonito en la costa del Perú - Años: 1941 - 1961

desplazamiento hacia el sur de la Contracorriente Ecuatorial.

Como ya se ha dicho, se admite que de Salaverry al norte el bonito es escaso, correspondiéndole una producción de 6% en promedio. El más alto porcentaje le corresponde a la zona centro, con el 82,2% de la producción total; es aquí donde existe el mayor número de puertos pesqueros y está concentrada la flota bonitera. Al sur de Pisco, la costa se caracteriza por las playas abiertas, con escasos lugares de desembarque y con sólo un puerto pesquero de importancia, Ilo; el rendimiento de esta zona, con 11,8% de la producción total, a nuestro criterio no refleja la abundancia de bonito en esta área, en que grandes cardúmenes son avistados con frecuencia.

El Cuadro III y la gráfica de la Fig. 5 se refieren al rendimiento comparativo de estas zonas.

5.3 Composición de la pesca

El bonito entra en la pesquería cuando adquiere 25 cm. de longitud (a la horquilla); el tamaño promedio de la chauchilla es de 30 cm.; el del cerrajón, de 40 cm., y el del bonito adulto, 60 cm. Durante la temporada de pesca, de octubre a marzo normalmente, las capturas consisten casi exclusivamente en bonito adulto, que también se pesca en el resto del año, período en que la chauchilla y el cerrajón son frecuentes.

Los cardúmenes de bonito tienden a agruparse por grupos de tamaños, y generalmente excluyen a otras especies. Esto se constata en la pesca que realizan los boliches, cuya selectividad es mucho menor que la de las redes agalleras.

Se calcula que en el desembarque total de la especie, el 95% corresponde al bonito adulto, y el 5% restante a los tamaños menores.

5.4 Distribución de la producción

El 30% de la producción total es consumida en fresco; 10% se somete a la salazón, y el 60% restante se utiliza en la fabricación de conservas que elaboran las 32 fábricas en actual funcionamiento. La producción actual de conservas es de 25.000 toneladas métricas, de las cuales el 20% se consume en el país y el resto se exporta.

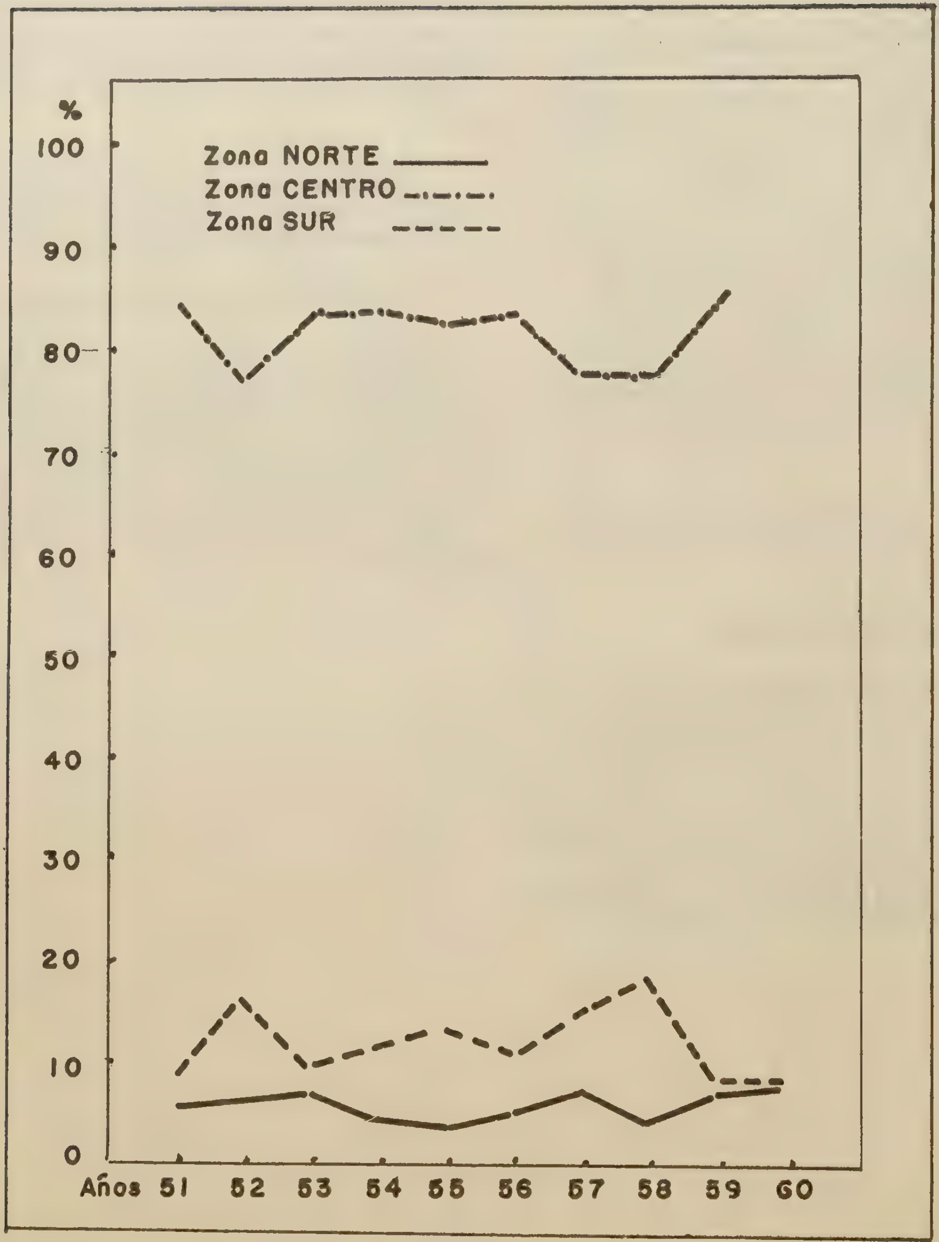

Fig. 5 Gráficas comparativas del desembarque de bonito por zonas - Años: 1951 a 1960

Cuadro III

Cifras de desembarque de bonito por zonas 1/ - Años: 1951 a 1960
Kilogramos

Años	ZONA NORTE		ZONA CENTRO		ZONA SUR		TOTALES
	Pesca	%	Pesca	%	Pesca	%	Pesca
1951	2.980.677	5,9	43.230.261	85,1	4.557.679	9,0	50.768.617
1952	3.135.315	6,2	38.678.927	77,2	8.315.428	16,6	50.129.670
1953	3.096.869	7,1	36.382.133	83,3	4.216.053	9,6	43.695.055
1954	2.461.402	4,7	43.823.576	83,8	6.034.837	11,5	52.319.815
1955	2.803.037	3,9	58.900.006	82,7	9.488.170	13,3	71.191.213
1956	4.445.895	5,3	69.667.729	83,5	9.313.325	11,2	83.426.949
1957	4.373.725	7,6	44.778.447	77,6	8.572.886	14,8	57.725.058
1958	2.829.045	4,3	50.838.574	77,3	12.090.658	18,4	65.758.277
1959	5.688.774	7,0	69.425.088	84,8	6.704.615	8,2	81.818.477
1960	7.441.995	7,7	81.167.185	84,3	7.687.696	8,0	96.296.876
TOTAL	39.256.734	6,0	536.891.926	82,2	76.981.347	11,8	653.130.007
PROMEDIO	3.925.673	6,0	53.689.193	82,2	7.698.135	11,8	65.313.001

1/ Zona Norte - Máncora a Salaverry
Zona Centro - Chimbote a Pisco
Zona Sur - San Juan a Ilo

Experience Paper No. 36

THE OLFACTORY ORGAN OF THE SKIPJACK Katsuwonus pelamis

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Abstract

The morphology and histology of the olfactory organ of the skipjack tuna Katsuwonus pelamis (Linnaeus) are described. The olfactory apparatus consists of an olfactory chamber, containing an olfactory rosette, and an accessory sac which functions as a pumping apparatus. No cilia are present. Olfactory sensory hairs on the rosette epithelium were demonstrated.

Experiments to determine the flow of water through the olfactory apparatus demonstrated that water flows through the olfactory chamber owing to forward progression of the fish, and that an additional increment of water is probably drawn into the chamber by the accessory sac when the jaws are opened.

It was concluded that the skipjack has a potentially functional olfactory organ.

L'ORGANE OLFACTIF DE LA BONITE A VENTRE RAYE Katsuwonus pelamis

Résumé

On décrit la morphologie et l'histologie de l'organe olfactif de la bonite à ventre rayé, Katsuwonus pelamis (Linnaeus). L'appareil olfactif comprend une chambre olfactive, contenant une rosette olfactive, et un sac accessoire qui fonctionne comme une pompe. Il n'y a pas de cils. L'article décrit la chevelure sensorielle olfactive de l'épithelium de la rosette.

Des experiences destinées à mesurer le passage de l'eau à travers l'appareil olfactif a montré que l'eau passe dans la chambre olfactive grâce au mouvement du poisson, et qu'une quantité supplémentaire est probablement amenée dans la chambre par le sac annexe lorsque la bouche du poisson est ouverte.

On en conclut que la bonite à ventre rayé a un organe olfactif potentiellement fonctionnel.

EL ORGANO OLFATORIO DEL BARRILETE *Katsuwonus pelamis*

Extracto

Se describen la morfología e histología del órgano olfatorio del barrilete *Katsuwonus pelamis* (Linnaeus). El aparato olfatorio consiste en una cámara en la que se aloja la roseta olfatoria y un saco accesorio que funciona como una bomba. No existen cilios. Se ha demostrado la existencia de pelos sensoriales olfatorios en el epitelio de la roseta.

Los experimentos para determinar el paso del agua por el aparato olfatorio han demonstrado que ésta fluye por la cámara debido al movimiento de avance del pez, y que es probable que al abrir la boca aumente la entrada de agua en la cámara por efecto del saco accesorio.

Se ha llegado a la conclusión de que el barrilete tiene un órgano olfatorio factible de funcionar.

1 INTRODUCTION

The skipjack tuna, Katsuwonus pelamis (Linnaeus), has no precise morphological or histological description of its olfactory organ recorded in the literature. Burne (1909) provided a relatively limited, concise description of the general anatomy of the olfactory organs of a number of fishes, including Scomber scombrus. Kishinouye (1923) included a very brief and generalized account of the olfactory organ of several scombroids, including the Katsuwonidae.

The purposes of the present investigation are (1) to describe the morphology and histology of the skipjack olfactory organ, and (2) to determine the path of water through the olfactory apparatus and the mechanisms involved in the process.

2 MATERIALS AND METHODS

2.1 Field methods

The skipjack used for histological study were collected from the fishing sampan Buccaneer, of Honolulu, Hawaii.

In order to prevent autolysis the material was placed in a fixative within a few minutes after the fish had been caught. The procedure was to remove the forward part of the head just anterior to the eyes, split the excised section of the head sagittally on the median plane, and make two incisions into the olfactory chamber, along the upper edge of the lacrymal bone and between the external nares. The specimen was then immediately put in a fixative. The above technique permitted rapid penetration and produced satisfactory results for most tissue, but it was not rapid enough to preserve the delicate olfactory sensory hairs. To preserve the olfactory hairs the olfactory rosette was removed from the chamber and placed in 7 percent formalin in Ringer's solution immediately after the fish was landed. A number of fixatives were used. These were 10 percent formalin, 7 percent formalin in Ringer's solution, Bouin's fluid, Gilson's fluid and Zenker's fluid. In addition, olfactory epithelium placed in Ringer's solution immediately after removal from a live fish was stained lightly with methylene blue and examined for the presence of cilia by a method described by Hopkins (1926).

2.2 Laboratory methods

Tissue fixed in the formalin solution, Bouin's fluid, or Gilson's fluid could be left in the fixative for several weeks without being impaired in quality. Material fixed in Zenker's fluid was transferred after 12 hours, through 35 percent and 50 percent ethyl alcohol to 70 percent alcohol. If it remained in the fixative for longer than 12 hours the cells seemed to undergo excessive shrinkage. Mercuric crystals were removed from the Zenkerized sections by a 15-minute treatment with iodized alcohol.

Standard methods of clearing, imbedding, sectioning, and staining were followed, but some experimentation and modification were necessary to obtain satisfactory results.

Both ethyl alcohol and dioxane were used as dehydrating agents. Alcohol gave consistently good results, but a large proportion of tissue dehydrated with dioxane was too brittle for sectioning.

Cedarwood oil was the best clearing agent used. No hardening effect was observed, and the relatively slow infiltration of paraffin was accompanied by very little shrinkage. Both xylol and benzol had a hardening action and considerable shrinkage was observed with xylol during paraffin infiltration.

A medium grade of paraffin with a melting point of 56° C was used. Epithelial tissue, such as the rosette, was completely impregnated after 1.5 hours, whereas denser connective tissue required about 2.5 hours for complete infiltration.

All sections were cut at 6μ.

Heidenhain's hematoxylin and Harris' hematoxylin, counterstained with eosin, both gave satisfactory results. Heidenhain's hematoxylin stained better if the iron-alum mordant was allowed to act for 12-24 hours. Krichesky's modification of Mallory's triple stain, described in Jones (1950), and Van Gieson's connective tissue stain with Weigert's iron hematoxylin were used as differential stains.

3 MORPHOLOGY

Osteological terms in the following description are taken from Gregory (1933).

The external anatomy of the olfactory system fits into the general streamlining of the skipjack, offering little resistance to the flow of water past the head (Fig. 1). The anterior naris is a small circular opening, about 0.3 mm in diameter on a fish about 45 kg in weight and 72 cm in fork length. A mound of skin behind the anterior opening projects about 0.3 mm from the head surface, and in effect forms a hood which gives the external nostril an anteriorly directed aspect. The passage into the capsule from the anterior naris is roughly perpendicular to the surface of the head. The posterior naris, 1.7 cm behind the anterior naris, is an elongated vertical slit, 1.4 cm in length with its upper extremity slightly ventral to the anterior naris (Fig. 1). The slit-like opening is directed posteriorly, with its interior passage leading obliquely forward into the olfactory chamber. A posteriorly directed flexible lip of skin overlaps the slit and potentially serves as a one-way valve against ingress of water.

The olfactory chambers, Fig. 2, lie in depressions of the ethmoid bone, bounded above by the nasal bones. On each side the chamber extends posteriorly from immediately caudal to the anterior process of the nasal bone, above the upper surface of the palatine bone, to the anterior rim of the orbit. Below the chamber and extending a little posterior to it there is an accessory sac or chamber. This accessory sac is bounded laterally by the lacrymal bone and extends posteriorly from the anterior margine of the lacrymal, parallel and mesial to its inner surface, to a point lateral and ventral to the palatine-pterygoid suture. The palatine bone and the buccal membrane delimit the sac mesially and ventrally. An elongate opening about 11 mm long and 4 mm wide between the palatine and lacrymal connects the accessory sac and olfactory chamber (Fig. 2). The entire length of the accessory sac lies above the maxillary bone, by which the sac is compressed when the mouth is closed and expanded when the mouth is open.

An olfactory rosette (Fig. 2) is located directly beneath each anterior naris. Its axis, perpendicular to the head surface, is attached anteriorly to the inside lip of the narial opening. Olfactory leaves about 5 mm in length, with their plane surfaces perpendicular to the head surface, radiate posteriorly from the axis through an arc of about 180°. A few of the most dorsal leaves are beneath the nasal bone, but most of the rosette is under the fleshy roof of the olfactory chamber. The number of leaves varies between fishes and between capsules in a single specimen. In 38 rosettes the number ranged from 34-47 per rosette. The leaves form a pit-like indentation where they join the rosette axis just mesial to its juncture with the lip of the naris. Water passing into the anterior naris would be directed into this pit and would flow along the epithelial surfaces of the leaves to enter the olfactory chamber. The mesial borders of the rosette leaves are firmly attached to the membrane which lines the olfactory capsule and, according to Allison (1953), are complex folds of that tissue.

Numerous small nerve trunks leave the base of the rosettes and form larger trunks, the olfactory nerves, which pass through foramens in the ethmoid into the cranial cavity prior to their juncture with the olfactory bulbs. A trunk of the trigeminal nerve also passes through the ethmoid and apparently innervates the lining of the chamber, but no branches were found leading from the rosette proper. In vertebrates the profundus ophthalmic branch of the trigeminal nerves is known to supply fibers to the nasal area (Allison, 1953; Weichert, 1951).

The fleshy roof overlying the olfactory chamber extends from the dorsal border of the lacrymal to the lateral edge of the nasal, and from the anterior edge of the rosette to the posterior naris (Fig. 2). The area immediately overlying the rosette consists primarily of the dermis, but the tissue overlying the rest of the chamber consists of two elongate mounds which bulge inward from the outer dermis (Fig. 2). The upper mound extends from immediately posterior to the rosette to the posterior naris. The lower mound parallels the upper mound and extends to the posterior naris. Anteriorly the two mounds form a cavity into which the rosette fits. A narrow channel running between the mounds opens into the posterior naris. The lower mound is parallel to the antero-dorsal margin of the lacrymal and fits closely over the opening between the accessory sac and the olfactory chamber (Fig. 2).

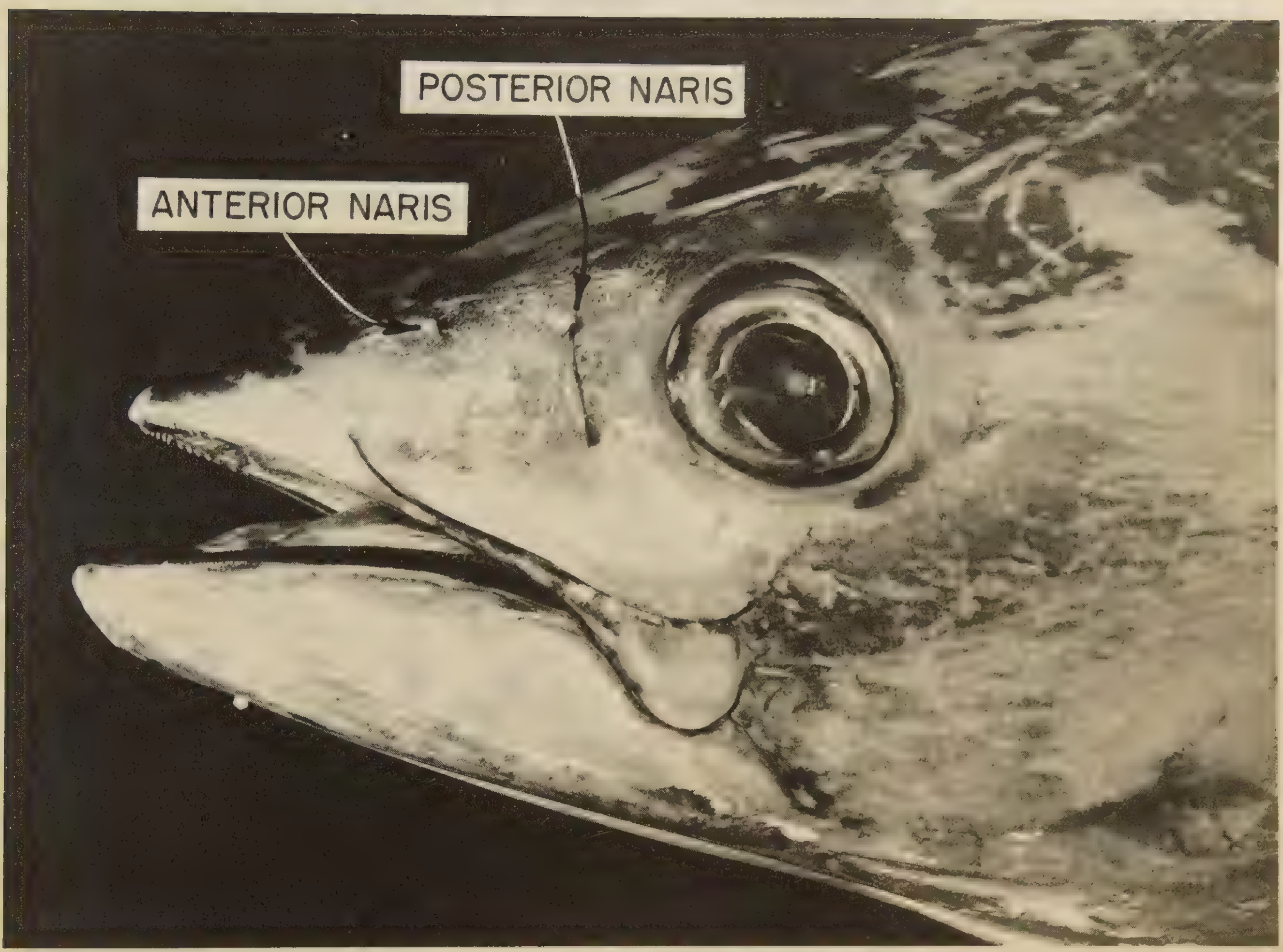
POSTERIOR NARIS
ANTERIOR NARIS

Fig. 1 Skipjack's external nares

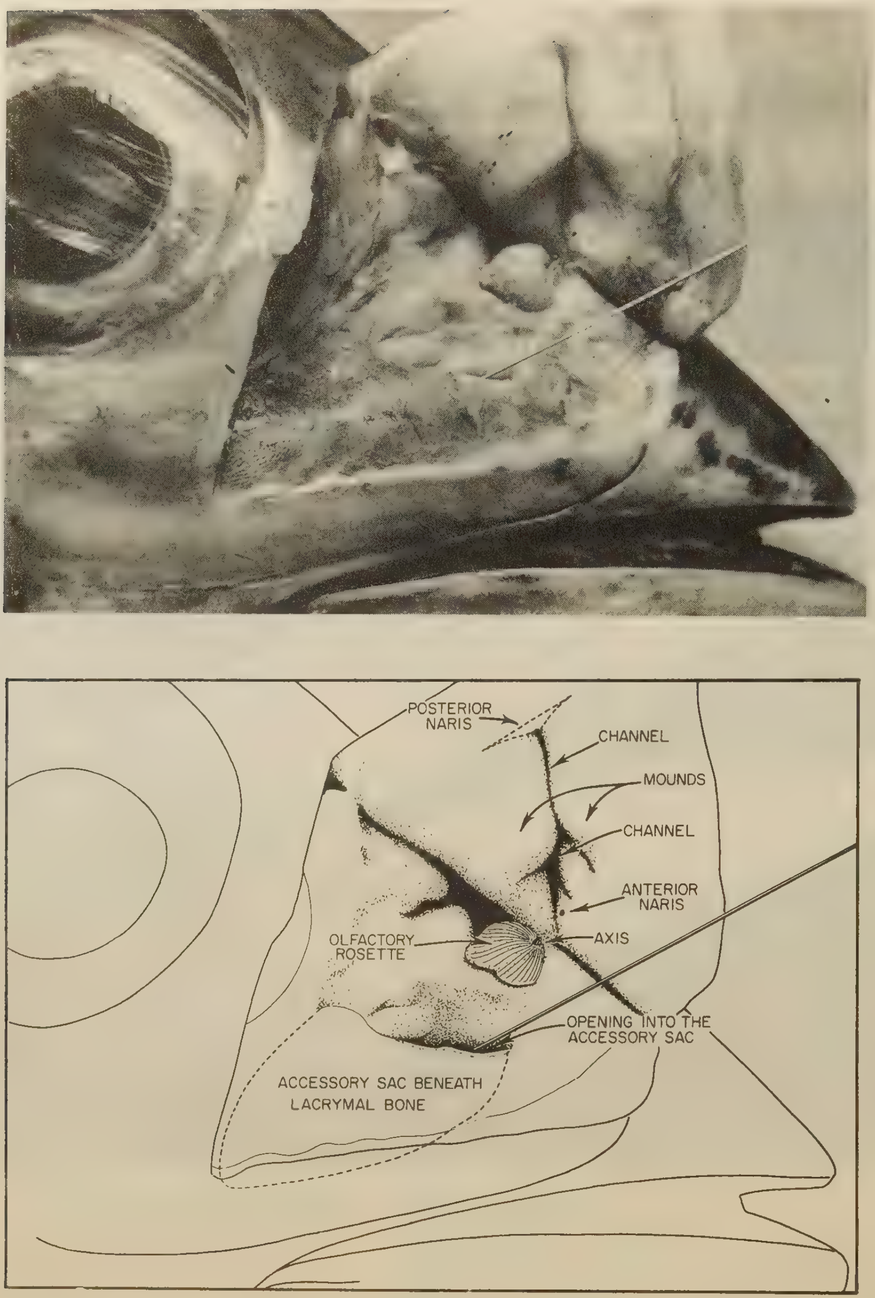
POSTERIOR NARIS
CHANNEL
MOUNDS
CHANNEL
ANTERIOR NARIS
AXIS
OLFACTORY ROSETTE
OPENING INTO THE ACCESSORY SAC
ACCESSORY SAC BENEATH LACRYMAL BONE

Fig. 2 Olfactory chamber

4 HISTOLOGY

The olfactory chamber and accessory sac are lined with mucous membrane. On the mesial wall of the chamber this lining consists of stratified squamous epithelium overlying a fatty stroma richly supplied with small blood vessels. The olfactory nerve runs from the rosette through this underlying stroma before passing through the ethmoid. The membrane lining the accessory sac is less fatty and not as highly vascularized as the membrane of the olfactory chamber. The two mound-like protuberances on the lateral walls of the chamber consist predominantly of white fibrous connective tissue. Chromatophores are scattered in the membrane lining the walls of the chamber but are not found on the membrane lining the accessory sac. The lip of the anterior naris is a continuation of the squamous epithelium of the dermis but is non-cornified.

The rosette axis consists mainly of a moderately loose, collagenous connective tissue (Fig. 3). The rosette leaves branching out from the axis are formed of an outer layer of pseudostratified epithelium and an inner collagenous stroma similar to the stroma of the axis. Occasional scattered groups of chromatophores occur on the distal margins of the leaves. The epithelium on the proximal portion of the leaves, about three-quarters of the distance from the axis to the extremity of the leaf, is a typical pseudostratified olfactory epithelium about 50μ thick (Fig. 3).

The olfactory epithelium of the leaves is composed of three distinct cell types: supporting cells, basal cells, and olfactory sensory cells. The supporting or sustentacular cells, Fig. 4, are columnar and non-ciliated. Their basal processes extend down into the supporting reticulum underlying the epithelium and their free borders are exposed to the chamber. Oval nuclei of the sustentacular cells are located about midway between the surface and base of the epithelium. The basal cells are in close conjunction with the basal reticulum (Fig. 3). Their nuclei are small and stain darkly. No distinct basement membrane is apparent. Interspersed between supporting cells are a smaller number of olfactory sensory cells (Fig. 4). These are spindle-shaped cells with a round nucleus in the basal portion. The distal part of the cell body reaches nearly to the surface. A slender process (the dendrite) passes through the epithelial surface and continues as the so-called olfactory hair into the olfactory chamber. In the preparations examined a single hair extends 8-15μ from each cell. Much finer processes (the axons) run from the basal portions of the olfactory cells. They pass between the supporting cells and enter the basal reticulum, but could not be traced any farther.

Axons from the sensory olfactory cells apparently combine to form the nerve fasciculi present in the central stroma of the rosette leaves (Fig. 3). Fasciculi are located in the leaves, and around the periphery of the axis. They extend parallel to the axis, and the individual bundles become progressively larger towards the distal portions of the leaf. These fasciculi extend into the underlying stroma and form the small nerves which make up the olfactory nerve. No fasciculi are found in the outermost portion of the leaves, and the epithelium covering that area is somewhat thicker than the olfactory epithelium of the more proximal leaf surfaces (Fig. 3). No olfactory hairs are present beyond the area in which nerve fasciculi occur. The supporting stroma of the rosette leaves and axis is supplied with numerous venules, arterioles, and capillaries.

5 EXPERIMENTS TO DETERMINE WATER FLOW THROUGH THE OLFACTORY CHAMBER

The anatomy of the skipjack olfactory organ suggests that the accessory sac may pump water in and out of the olfactory chamber. A series of experiments was conducted to determine whether compression of the sac by jaw movements does increase water flow into the chamber, and also to determine whether water enters the chamber of a fish swimming at average speeds without jaw movements. The experiments were conducted using heads of fresh 45 kg skipjack obtained from the fish market.

5.1 Methods

Prior to each experiment the olfactory chamber and the nasal openings were cleaned of blood and mucous by gently inserting a blunt hypodermic needle into the posterior naris and injecting water into the chamber until it squirted from the anterior naris. The heads were then placed in standing or flowing water dyed with

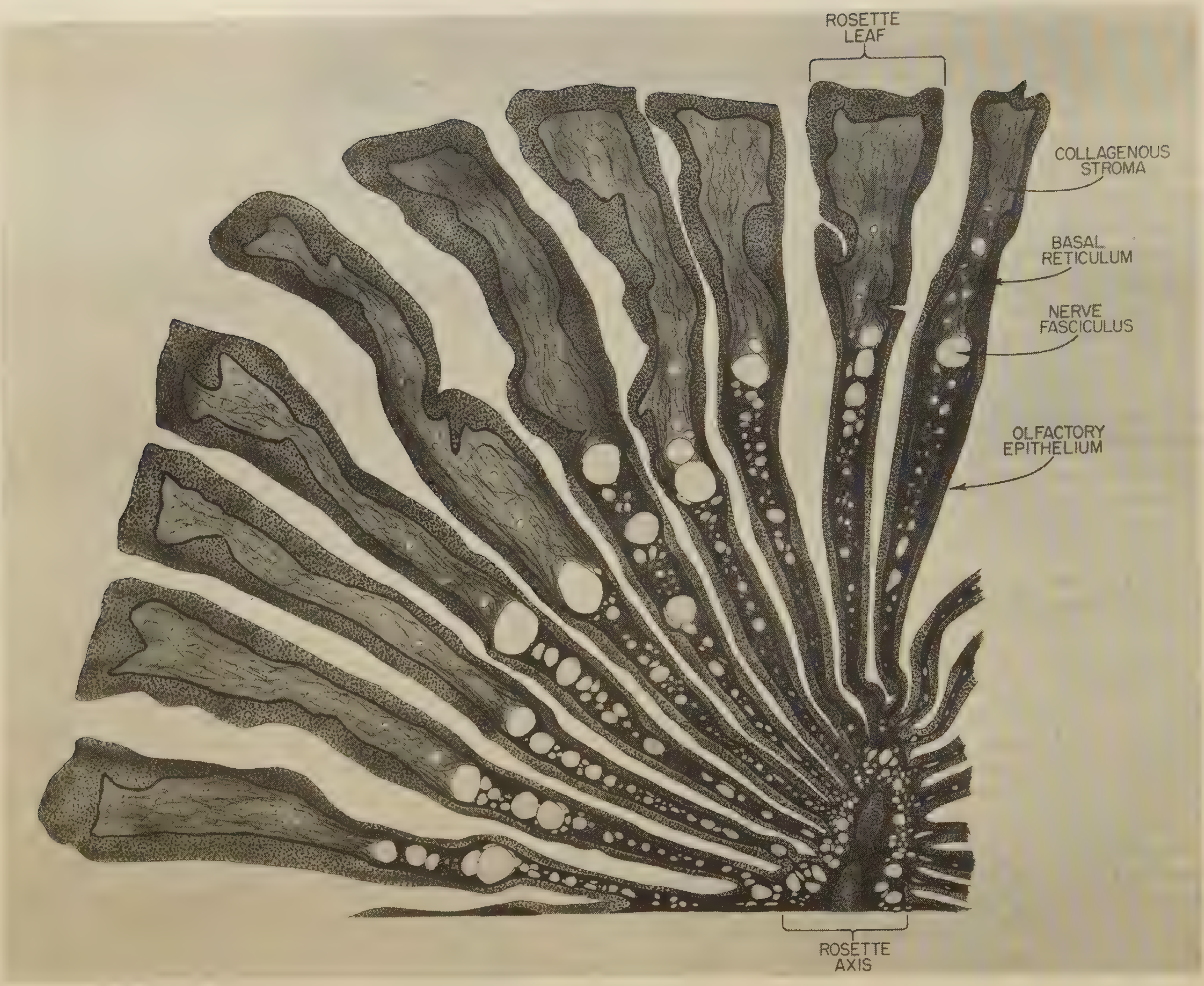
ROSETTE LEAF
COLLAGENOUS STROMA
BASAL RETICULUM
NERVE FASCICULUS
OLFACTORY EPITHELIUM
ROSETTE AXIS

Fig. 3 Cross section of a segment of the olfactory rosette and axis. 150 X

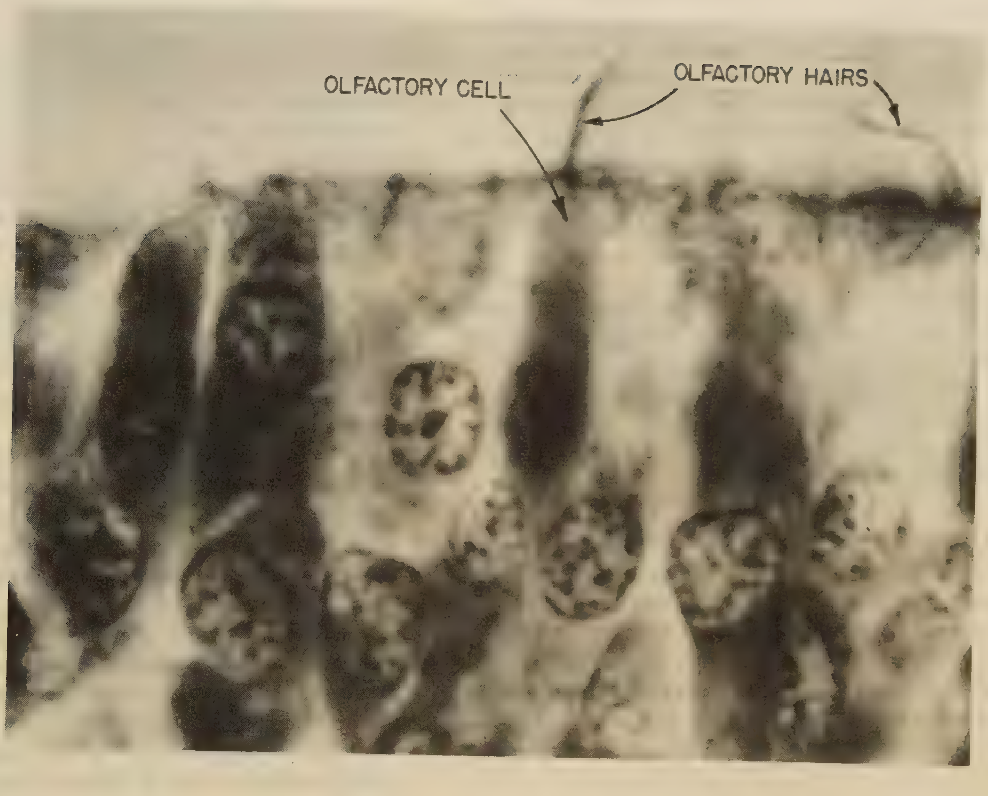
OLFACTORY CELL
OLFACTORY HAIRS

Fig. 4 Section of a skipjack's olfactory epithelium, showing the supporting cells and the olfactory cells with their associated sensory hairs. 950 X

methylene blue. The amount of dye entering the olfactory chamber, determined qualitatively by inspection, was used as a measure of the quantity of water entering in the different treatments. The current velocity used in the experiments (300 cm per second) corresponds to average swimming speeds observed in feeding skipjack at sea.[1/] The influence of jaw movements was measured both in the standing and flowing water tests. Jaws were either held stationary or worked up and down by the experimenter.

5.2 Results

Tests on 17 fish held in flowing water indicated that the same amount of water entered the chamber when the jaws were worked or held stationary. Tests on 8 additional fish heads in standing water indicated that much more water entered when the jaws were worked than when they were held stationary.

In another experiment the olfactory chamber was filled with dye and it was observed that in still water small spurts of dye were ejected from the posterior naris when the jaws were closing, whereas almost no dye came from the anterior naris. In flowing water dye was ejected from the posterior naris when the jaws were worked, but none was ejected from the anterior naris.

A final test was made to determine whether the flap on the posterior naris acted as a one-way valve allowing water to exit but not enter. Heads were held in a current and either the posterior or anterior naris was occluded. Water entered the chamber when the posterior naris was occluded, but did not enter when only the anterior naris was occluded.

6 DISCUSSION

The anatomy of the olfactory apparatus of the skipjack is typical in general structure of fishes possessing accessory sacs. According to Burne (1909), the position of the olfactory chamber relative to the bones of the head and the location of the rosette directly below the anterior naris are almost universal. The relationships between the accessory sac and the associated maxillary bone, the mound-like structure on the lateral wall of the chamber, and the valved posterior naris are of particular interest in the skipjack. The ventral mound fits closely over the opening between olfactory chamber and accessory sac and apparently serves as a valve between them. Opening the jaws depresses the maxillary in a manner that increases the volume of the accessory sac and closing the jaws has the opposite effect. This system could be expected to function as a bellows-like pump. The structure of the posterior naris resembles a one-way valve, permitting little or no entrance of water.

Skipjack observed in the tanks at the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, occasionally open and close their mouths with a snapping movement. This is not necessarily feeding behavior, as the movements are made even when the fish are not eating, nor is it probable that it can be considered mating behavior, as the fish are sexually immature. Skipjack normally swim with their mouths slightly agape (Nakamura, in press), permitting a free flow of water over the gills. Hall (1930) showed that in the mackerel, Scomber scombrus, the O_2 saturation in the blood decreased from 85 percent in a free-swimming fish to 11 percent in a closely confined fish. The respiratory current is apparently developed through forward progression, and it appears unlikely that any gill or jaw movements are required for respiration.

On this basis we feel that these snapping movements may be the equivalent of a sniff, which draws additional water into the olfactory chamber. It is possible that the movements are made more frequently at slow swimming speeds when a relatively small volume of water is passing through the chamber.

It is interesting to compare the olfactory sensory hairs of the skipjack with those demonstrated by previous workers. Jagodowski (1901) observed that sensory hairs may be twice as long as the olfactory epithelial cells in the pike, Esox lucius. In the frog, Rana, 4-6 hairs extended 150μ or more beyond the epithelium (Hopkins, 1926). In the scup, Stenotomus chrysops, Hopkins found scattered olfactory

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1/ These speeds were calculated in our laboratory from underwater motion pictures taken of feeding skipjack from the viewing chamber of the research vessel Charles H. Gilbert.

hairs 20-30μ long, and there appeared to be more than one hair to a cell.

Sensory hairs in the skipjack are seldom more than 10μ long, and apparently there is only one to a cell. Considerable difficulty was encountered in demonstrating the olfactory hairs, and the hairs which were demonstrated quite often had a truncated appearance. Parts of these delicate structures may have been destroyed during processing of the tissue. Further perfection of technique may demonstrate the existence of longer hairs, and possibly of more than one to a cell.

Van Weel (1952) observed that little tunny (Euthynnus yaito) and yellowfin tuna (Neothunnus macropterus) held in captivity responded to clear extracts of tuna flesh. He concluded that a chemical sense is present, but could not say whether it was a sense of smell or taste. Tester et al (1954) continued these experiments and obtained very positive responses from little tunny (Euthynnus affinis). They felt that there was no doubt the response was through the fish's sense of either smell or taste.

The results of this study show that skipjack possess a potentially functional olfactory apparatus, and that the sense of smell could account for at least part of any chemoreceptive abilities of this species.

On the basis of the anatomy and histology of the skipjack's olfactory apparatus and the results of the experiments, the conclusions are that a continuous stream of water flows slowly through the olfactory capsules of a swimming skipjack, entering through the anterior nares and exiting through the posterior nares, and that an additional increment of water is probably drawn in via the anterior nares when the mouth is opened and is ejected via the posterior nares when the mouth is closed, especially when the fish is swimming at slow speeds.

Experience Paper No. 37

THE PAST, PRESENT AND FUTURE STATUS OF THE TUNA RESOURCES OF THE TRUST TERRITORY OF THE PACIFIC ISLANDS

By

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Abstract

The live-bait tuna resources of the Trust Territory of the Pacific Islands are presently undeveloped but capable of yielding 50,000 tons (100,000,000 pounds) of skipjack (Katsuwonus pelamis) annually.

During the 1930's the Japanese established fishing bases in Palau, Truk, Ponape and Saipan and produced substantial catches of skipjack each year prior to the outbreak of the second world war.

From the end of the second world war until 1955, very little was done to develop the marine resources of the Trust Territory. In recent years a fisheries station has been erected and the development of the inshore and offshore marine resources started.

The Fisheries Program of the Trust Territory is now being enlarged, new bases are being planned and erected, a shipyard is being constructed, and training programs are in effect. Negotiations with members of the American Tuna Industry have been held and proposals for the development of tuna fishing operations in the Trust Territory are now under consideration.

L'ETAT PASSE, PRESENT ET FUTUR DES RESSOURCES EN THON DANS LE TERRITOIRE SOUS MANDAT DES ILES DU PACIFIQUE

Résumé

Les ressources en thon pêché à l'appât vivant dans le Territoire sous mandat des îles du Pacifique n'ont pas été jusqu'à présent développées et elles pourraient fournir annuellement 50.000 tonnes de bonite à ventre rayé (Katsuwonus pelamis).

Dans les années 30, les centres de pêche installés par les Japonais à Palau, Truk, Ponapo et Saipan ont fourni chaque année des quantités substantielles de bonite à ventre

rayé, avant l'interruption amenée par la seconde guerre mondiale.

Depuis la fin de cette guerre jusqu'en 1955, on a fait peu de chose pour développer les ressources marines du Territoire sous-mandat. Au cours de ces dernières années, on a installé une station de pêche et lancé le développement des ressources marines, intérieures et de haute mer.

Le programme des pêches du Territoire sous-mandat est en train d'être élargi, on prévoit et on établit de nouveaux centres de pêches, on construit un chantier naval et on applique des programmes d'entraînement. On a conduit des négociations avec les membres de l'industrie américaine du thon et on étudie actuellement des propositions pour le développement des opérations de pêche au thon dans le Territoire sous-mandat.

SITUACION PASADA, PRESENTE Y FUTURA DE LOS RECURSOS DE ATUNES EN EL TERRITORIO EN FIDEICOMISO DE LAS ISLAS DEL PACIFICO

Extracto

En el territorio en fideicomiso de las islas del Pacífico, los recursos de atunes factibles de ser pescados con cebo vivo no se explotan por completo, pero son capaces de rendir 50.000 tons de barrilete (*Katsuwonus pelamis*) al año.

En los años anteriores a la segunda guerra mundial, los japoneses establecieron bases pesqueras en Palau, Truk, Ponape y Saipan y lograron importantes capturas anuales de barrilete hasta la ruptura de las hostilidades.

Desde que acabó la segunda guerra hasta 1955, se hizo muy poco para explotar los recursos marítimos del territorio. En los últimos años se ha construido una estación pesquera y se ha iniciado la explotación de los recursos costeros y de media altura.

El programa de pesca del territorio en fideicomiso está siendo ampliado, se proyectan y construyen nuevas bases, se construye an astillero y están enpráctica programas de capacitación. Se han efectuado negociaciones con representantes de la industria atunera norteamericana y se estudian propuestas para el fomento de la pesca del atún en el territorio en fideicomiso.

1 THE SKIPJACK RESOURCES

With the exception of the Hawaiian skipjack fishery and subsistence fishing operations throughout the Pacific Islands, none of the surface skipjack fisheries of Oceania are being harvested at this time.

With the rapidly growing world demand for tuna, these fisheries will become increasingly important during the coming years. For this reason, plus the fact that the marine resource must be considered as one of the most important economic resources of the Pacific, it is the intention of the Trust Territory to develop the fisheries of this area in such a manner that Micronesians will be the ones to derive the most benefit from the resource in future.

Such a development requires considerable knowledge of the resource. Much of our knowledge of the Trust Territory's offshore fisheries comes from the Japanese, who administered the area between the first and second world wars.

At the end of the first world war, Japan acquired Germany's holdings in the Pacific and throughout the 1920's spent considerable time and money evaluating the resources of the area. During the early 1930's, fishing bases were established in Palau, Truk, Ponape and Saipan and commercial tuna fisheries of some magnitude rapidly developed. Both longline and livebait fishing operations were carried on, but fish caught by longline was landed in Japan and hence does not appear in local catch statistics. The skipjack harvest has been accurately recorded, however, and from these figures we learn that Palau and Truk each produced between 11, 000, 000 and 30, 000, 000 pounds of fish every year.

Ponape's production was not as great, but quite substantial. Annual production was 8, 000, 000 to 9, 000, 000 pounds of skipjack.

Saipan, with its limited bait supply, produced 4, 000, 000 to 8, 000, 000 pounds of skipjack each year.

Although Jaluit, in the Marshall Islands, is reported to have an abundance of bait, no commercial catches of skipjack were reported in this area except during 1938, when nearly 15, 000, 000 pounds were reported as being landed there.

The development of the skipjack resources of Micronesia reached its peak during 1937 when 35, 000 metric tons (75, 000, 000 pounds) were produced in Palau, Truk, Ponape and Saipan. Estimates have been made that the production of longline-caught tuna was at least equal to this figure. This would mean 70, 000 metric tons or 150, 000, 000 pounds of tuna were produced in Micronesian waters during that year.

The Japanese-Chinese conflict started shortly after that and fuel shortages reportedly reduced tuna production considerably, although Truk produced nearly 8, 500 tons (17, 000, 000 pounds) of skipjack in 1939.

It is not likely that the peak skipjack production figure of 35, 000 metric tons, reached by the Japanese in 1937, represents the limit of the skipjack fishery. Estimates were made by the Japanese that a livebait fishery of 100, 000, 000 pounds (50, 000 tons) would be quite possible.

2 THE BAIT RESOURCES

There appears to be an adequate bait supply in the Palau and Truk districts, especially when one considers the annual harvest of skipjack during the Japanese period. However, information on the bait resources of Palau, Truk, Ponape and Saipan is inadequate and incomplete. Positive identification of the former bait species from the existing literature is not possible, but an indication of the more valuable species can be obtained.

Four bait species have been found in Palau which were probably used in the Japanese fishing operations. Two of these are easily taken with a night-light and net, but their abundance appears seasonal. One is a member of the family Engraulidae, genus Stolephorus. The second is the round herring Spratelloides delicatulus. Species which are easily taken with day-bait nets are an atherinid, Allanetta woodwardi, a sardine-like fish, Harengula punctata and several species of apogonids which were considered very good bait by the Japanese.

Several of the same bait species have been taken in Truk but there has been no intensive bait studies made in this area.

The bait fish resources of Ponape also need investigation. Mention is made, in Japanese literature, of a sardine-like species which lives among the mangroves. This is probably

Harengula punctata or a closely related species. No mention is made of Spratelloides delicatulus but it is common throughout these latitudes and very likely found around Ponape.

The bait resources of Saipan are limited and reported to be inadequate for commercial fishing operations from September to February. The most important bait species is probably Spratelloides delicatulus. It is common in this area, spawns around January and is reportedly not good for bait during this period. A second species was also reported as being an important bait fish, but its identification is questionable. Other bait species were also reported, but their identification is uncertain and they were apparently used only when the two previous species mentioned were not available.

3 THE FISHING VESSELS

Available Japanese records do not show the number of fishing boats based in each area. Palau has about 40 live-bait tuna boats; Truk, probably a few less. These were 15 to 50 tons, carrying about 20 crewmen. When bait and skipjack were abundant, boats often made two fishing trips a day. This fishing was done almost exclusively by Okinawans.

After war began in the Pacific, there was no recorded commercial tuna production from any Japanese fishing bases. Fishing probably continued on a reduced scale only to supply food for military occupation forces.

After the second world war, the U.S. Navy administered the Trust Territory until 1951. During this period a number of surveys were made and several sunken Japanese tuna boats were raised and put back into operation with local crews. These operations lasted only a short time as the boats had to operate with inexperienced crews, inadequate fishing gear and maintenance facilities, no dockside facilities, no ice or refrigerated storage space, no fuel or water facilities and no access to a market large enough to absorb their production.

4 PROGRAMS FOR FISHERIES DEVELOPMENT

When the U.S. Department of the Interior succeeded the Navy in the administration of what had been the Japanese Mandated Islands, fisheries development lay dormant until 1955. This was primarily due to a lack of funds and the administration's attitude that the development of the fisheries should be on a subsistence level. It was also felt that building up the tuna resources would not be possible with the limited Trust Territory budget. Added to these factors was the policy of not allowing outside capital to assist with the development of any of the resources of the area.

A step was finally made in the right direction when permission was given to the George Vanderbilt Foundation to send a survey team to the Trust Territory to collect marine and fresh-water fauna for classification.

In 1956 another move was made toward developing the marine resources of the Trust Territory when Dr. John McGowan was engaged to carry out a Territory-wide trochus investigation. Shortly after, another marine biologist, Reginald Gaines, was hired. He was given the job of developing the fishery resources of the Trust Territory. Starting from nothing, he and a small crew labored for the next several years to put up a dockside fisheries station on the site formerly occupied by the Japanese fisheries firm, Nanko Suisan. During this period he also organized the fishermen of Palau into an association and was instrumental in the formation of one of the first Fishermen's Co-operatives in the Trust Territory. He also began development of a School of Fisheries, a boat builders association, a sharp freezer and a small tuna cannery to supply the canned tuna requirements of the Trust Territory.

His untimely death delayed the development of these projects but with the exception of the cannery, which is scheduled to start packing during the coming year, they are now all in operation.

Other programs, such as education and fisheries, were examined. Directors of these and other activities were encouraged to upgrade their programs with the understanding that, if justified, additional funds would be obtained. Congress was approached for an increase in appropriation. While we are still uncertain about the outcome, the attitude of the Federal Government we definitely need more financial support to accomplish our mission in the Trust Territory.

How has this change in attitude affected the development of our tuna resources? The new administration has left little doubt that it wants quick results from Trust Territory programs. This is resulting in a stepped-up fisheries aimed primarily at developing the live-bait skipjack fisheries of the entire Trust Territory.

What about longline fishing as practiced by the Japanese so successfully throughout the world ? This method of fishing in the equatorial currents has proven to be good year round and Japanese vessels can usually be found fishing these waters. This type of fishing is commonly carried out by a group of vessels working together. In this manner they are able to locate current boundaries and fish much more effectively than they could by themselves. In this system, when a boat makes a poor catch on one day, it is able to relocate in a short period of time in a better fishing area by checking with the other boats to determine where the best catches are being made.

This type of fishing would present several problems if it were attempted on any scale throughout the Trust Territory with Micronesian crews. Initially, it would be difficult to get a sufficient number of fishermen and vessels operating so that they could fish together in the manner practiced by the Japanese. This would likely result in lower catches, longer trips, higher expenses and lower earnings.

Problems of disposing of that portion of the catch which would not be acceptable to tuna packers would also probably occur. If markets for these other species, such as marlins and extra large tunas, were available in areas other than the tuna markets, transportation difficulties would arise unless the volume was sufficient to warrant frequent callings of large reefer ships.

Another problem in developing a longline fishery would be getting Micronesians to stay at sea for the period of time required to fish the longline method effectively. Not having been brought up in this type of fishing, it is possible that difficulties would be encountered along these lines. Navigators and radio operators would have to be trained. Fishing vessels would have to be larger and more expensive than those for the live-bait fishery close to shore.

None of this is to say that longline fishing cannot be done effectively by Micronesians; we have done it on a limited basis in Palau. However, in the overall picture, it seems that longline development will be somewhat more formidable than developing the live-bait skipjack fishery. The latter lies close to shore, is a day fishery and will allow fishermen more time ashore.

Once the skipjack fishery is established and experienced fishermen are available, development of intensified long-lining can be commenced.

This, then, is the stage at which we presently find ourselves. In Palau we have a complete dockside fisheries station with ice plant, sharp freezer and storage reefer now in operation. We also have a School of Fisheries, a fisheries training vessel, and trainees in Hawaii learning commercial live-bait tuna fishing methods. Our shoreside facilities are adequate to support this training program and our inshore fishing operation, but hardly large enough to handle a fleet of skipjack boats operating commercially.

To develop the shoreside installations required in a commercial fishery, a shipyard is being constructed and a professional ship builder is being recruited to train the Palauan boat builders in fishing vessel construction and maintenance techniques. As soon as the boat shed, ways and equipment are ready, we plan to start building tuna boats similar to the style fished successfuly in Hawaii.

These boats are noted for their seaworthiness and stability and make an excellent working platform while hooking fish. They are designed for speed but not carrying capacity, as they are strictly engaged in a day fishery. They are diesel-powered, average about 75 feet in length, carrying about 50 buckets of bait, enough ice for one or two days' fishing and will carry 10 to 14 crew members.

A conspicuous feature of this type of sampan hull is a large clear working area aft of the wheelhouse, which gives the fishermen plenty of room in which to work freely. While fishing, all fishermen stand around the stern and the boat is kept moving slowly ahead. The Japanese and Okinawan method is to stop the boat in the water and fish from bow, sides and stern.

In Hawaii, the water in the bait wells is recirculated by the motion of the skip through holes of the well or by the usual overflow system. In the Trust Territory we plan on using the overflow system, since the water on the baiting grounds is usually very calm and the boats would have to keep moving in order to be assured of adequate circulation for their bait.

Once we start producing commercial quantities of tuna, we will require a large ice-plant and reefers of approximately 1,000 tons holding capacity to insure adequate storage.

For this reason, we have entered into negotiations with members of the American tuna industry in order to get these expensive shoreside facilities. As we are developing the entire fishery for the people of Micronesia, it has been necessary for the Trust Territory to firmly adhere to certain stipulations in our past dealings with industry which will insure that management and ownership of all shoreside fisheries facilities will eventually revert to Micronesians.

To interest industry in establishing expensive shoreside plants in the Trust Territory, volume landings of tuna must be made possible on, or shortly after, the completion of shoreside facilities. Initially, this can only be done by allowing foreign-flag vessels to land longline-caught tuna at the various plant sites. These landings will be supplemented by the Micronesian tuna fishery. Eventually, as the fishery develops, fishing and shoreside operations will be taken over by Micronesian fishermen, boats and personnel.

Transporting large quantities of tuna across the Pacific will prove costly. If too expensive, establishment of commercial fishing operations will be difficult. For this reason it may be necessary to utilize foreign-flag reefer ships to transport large quantities of tuna directly to the markets. This problem has been under consideration by both government and industry for some time. While no definite decision has been reached at this time, the outlook is promising, since the economic development of the Trust Territory is an acknowledged goal of the present administration.

Marketing the frozen or processed product is very important. It is not practical for the government, or Micronesians, to attempt to engage in such a highly competitive field at this time. Private industry - with its outlets, sales organizations, experience and excellent technical abilities - is in a much better position to handle this phase of the operation, and should do so.

The author has tried to present here a brief description of how we hope to develop the skipjack fisheries of the Trust Territory by training Micronesians as fishermen and boat builders, and by bringing in members of the American tuna industry to assist in setting up the required shoreside facilities.

It all sounds quite simple but there are many stumbling blocks and obstacles. More training is required, more boats needed, more fishing bases must be established, and certain laws must be modified or changed. Success will not be achieved as fast as we or the Micronesians would like.

We are now underway and, with the assistance of industry, should be able to ultimately develop the tuna resources to the point where they are a major factor in the economic well-being of the people of Micronesia.

Experience Paper No. 38

THERMAL RELATIONSHIPS OF TUNA IN THE OCEANIC NORTHWEST ATLANTIC

By

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Abstract

During 1957 to 1960 tuna explorations were conducted in the oceanic Northwest Atlantic by the U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries. Bathythermograph casts were made to a minimum of 137 meters at the 111 fishing stations. The area of exploration was centered about the Gulf Stream System, the major hydrographic feature of the oceanic Northwest Atlantic. Tuna abundance has been noted in areas of convergence and other current phenomena for the major oceanic circulatory systems. The Gulf Stream is analogous to the Kuroshio Current of the Northwest Pacific. The Gulf Stream System has been described in considerable detail, and oceanographic conditions that exist in this area appear to be conducive to the concentration of tuna resources. Similar concentrations of tuna have been described for the Kuroshio Current.

Observations were made on water temperature in relation to the occurrence of tuna species: bluefin tuna, Thunnus thynnus; yellowfin tuna, Thunnus albacares; albacore, Thunnus alalunga; bigeye tuna, Thunnus obesus; skipjack tuna, Euthynnus pelamis. Ranges and calculated means were determined for the observed water temperature, both at the surface and at an estimated fishing depth of 52.7 m. Mean water temperatures at the estimated fishing depth were determined for the major species to be: bluefin tuna - 15.5°C, albacore - 17.5°C, yellowfin tuna - 22.2°C. Observed water-temperature ranges indicate bluefin tuna to have the greatest range and yellowfin tuna the least. Observations for oceanic Northwest Atlantic tuna were compared to those of Dr. Uda's for the Northwest Pacific, and certain similarities for bluefin tuna and yellowfin tuna were noted.

RELATIONS ENTRE LA PRESENCE DU THON ET LA TEMPERATURE DE L'EAU DANS L'ATLANTIQUE DU NORD-OUEST

Résumé

L'U.S. Fish and Wildlife Service a conduit des recherches sur le thon de 1957 à 1960 dans l'Atlantique du Nord Ouest. Des relevés au bathythermographe ont été faits jusqu'à une profondeur minimum de 137 m sur 111 stations de pêche. La zone des explorations était à peu près centrée sur le système du Gulf Stream, le plus important phénomène hydrographique de l'Atlantique du Nord Ouest. L'abondance du thon a été notée dans les régions de convergence et les autres phénomènes courants pour les principaux systèmes circulatoires océaniques. Le système du Gulf Stream a été décrit en grand détail, et les conditions océanographiques qui existent dans cette zone paraissent contribuer à la concentration des ressources en thon. Des concentrations comparables ont été décrites pour le courant du Kuroshivo.

Des observations ont été rassemblées sur les relations entre la température de l'eau et la présence des espèces suivantes de thon: thon rouge, Thunnus thynnus, thon à nageoires jaunes, Thunnus albacora, thon germon, Thunnus alalunga, thon obèse, Thunnus obesus, bonite à ventre rayé, Euthynnus pelamis. Les intervalles de variation et les moyennes calculées ont été établis pour la température observée de l'eau, à la fois en surface et à la profondeur estimée de pêche de 52,7 m. Les températures moyennes de l'eau pour la profondeur estimée de pêche ont été déterminées pour les espèces principales: thon rouge, 15,5°C, thon germon, 17,5°C, thon à nageoires jaunes, 22,2°C. L'examen des intervalles de variation des températures observées indique qu'on a le plus grand intervalle pour le thon rouge et le plus petit pour le thon à nageoires jaunes. On a comparé les observations faites sur le thon dans l'Atlantique du Nord-Ouest à celle du Dr. Uda pour le Pacifique du Nord-Ouest, et on a pu relever certaines similitudes entre le thon rouge et le thon à nageoires jaunes.

RELACION ENTRE LA PRESENCIA DE ATUN Y LA TEMPERATURA DEL AGUA EN EL NOROESTE DEL ATLANTICO

Extracto

Desde 1957 hasta 1960, la Oficina de Pesca Industrial del Servicio de Pesca y Caza de los E.U.A. realizó exploraciones oceanográficas del atún en el noroeste del Atlántico. En 111 estaciones de pesca se emplearon batitermógrafos a profundidades mínimas de 137 m. La zona de exploración ten a por centro la corriente del Golfo, que es la principal característica hidrográfica del noroeste del Atlántico oceánico. Se ha observado abundancia de atún en puntos de convergencia y otros fenómenos de las corrientes en los principales sistemas circulatorios oceánicos. La corriente del Golfo es análoga a la corriente Kuro-sivo del noroeste del Pacifico. La corriente del Golfo se ha descrito con muchos pormenores y las condiciones oceanográficas que existen en ella parecen favorecer la concentración de recursos de atún. Se han descrito concentraciones análogas de atún en la corriente Kuro-sivo.

Se hicieron observaciones de la temperatura del agua con respecto a la presencia de las siguientes especies de atún: atún de aleta azul, Thunnus thynnus; atún de aleta amarilla, Thunnus albacora; albacora, Thunnus alalunga; patudo, Thunnus obesus y barrilete, Euthynnus pelamis. Las variaciones y medias calculadas se determinaron para la temperatura del agua observada, en la superficie y a una profundidad de pesca estimada en 52,7 m. Las temperaturas del agua medias y las profundidades de pesca estimadas se determinaron para las principales especies como sigue: atún de aleta azul, 15,5°C ; albacora, 17,5°C; atún de aleta amarilla, 22,2°C. Las variaciones de la temperatura del agua observadas indican que el atún de aleta azul tiene la mayor distribución y el de aleta amarilla la menor. Las observaciones sobre el atún oceánico del noroeste del Atlántico se compararon con las del Doctor Uda para el noroeste del Pacífico, observándose ciertas analogias en el caso de los atunes de aleta azul y aleta amarilla.

1 INTRODUCTION

The reasons for the accumulation of biota in specific oceanic areas have been the subject of considerable study for a long period of time. Observations of the commercial fishery and the findings of exploratory research indicate that specific oceanic areas are inhabited by an extensive tuna population. The productivity of these areas usually varies with the seasons. Fishery scientists are attempting to find the principles that control the distribution and abundance of tuna.

The determination of temperature preferences of various species of fish is a physical measurement of the marine environment that has received considerable attention for many years. Information on water temperatures, combined with other biological and physical data, is used in the development of fishery forecasts for tuna in the western and eastern Pacific.

Limited exploratory research for tuna in the oceanic Northwest Atlantic was conducted from 1957 to 1960 by the Bureau of Commercial Fisheries, North Atlantic Fisheries Exploration and Gear Research Base, Boston, Massachusetts. During this period, 111 stations were fished with modified Japanese longline gear by the exploratory fishing vessel Delaware in the area off the northeast coast of North America, from latitude 30° north to southwest of the Grand Bank and to the vicinity of the Island of Bermuda. The majority of exploratory stations were conducted at varying distances from the Gulf Stream, and at each station bathythermograph casts were made to a minimum of 137 m. Information on observed water temperatures in relation to captures of the several species of tuna is presented to illustrate the gross changes in species composition by seasons.

2 OCEANOGRAPHIC CHARACTERISTICS OF THE AREAS EXPLORED

Concentrations of tuna are known to be generally associated with convergent water masses, particularly those of the major oceanic circulatory systems. Research in the Pacific indicates a correlation between tuna abundance and the major circulatory systems of the Kuroshio or North Pacific current, the North and South Equatorial currents, and the counter currents (Uda 1953; Sette 1955). In many cases the areas yielding the greatest abundance of tuna during experimental fishing efforts have been located near the boundaries of these systems. In some cases these water masses are of such dissimilarity that visible, well-defined surface lines of convergence occur, and researchers in the western Pacific have long studied the relationship of tuna and other pelagic species of fish to these lines of convergence (Uda 1953).

In geographical positioning, the Delaware explorations in the oceanic Northwest Atlantic were conducted in the general area of the Gulf Stream (Fig. 1). The Woods Hole Oceanographic Institution has conducted extensive studies of this System over many years. However, in contrast to the extensive hydrographic information available on this area, little is known of the pelagic fish in or near the Gulf Stream System. This dynamic water mass is analogous to the Kuroshio Current of the Northwest Pacific. Therefore, we might expect a similarity in environmental conditions between these major current systems. Comparable tuna species of the oceanic Northwest Atlantic and of the Northwest Pacific having similar environmental requirements should show a resemblance in seasonal migratory patterns, though modified due to the effects of differences in current structure.

The Gulf Stream System is composed of the Florida Current from Tortugas to Cape Hatteras; the Gulf Stream from Cape Hatteras to the Grand Bank; and from this point eastward the North Atlantic Current. The Gulf Stream has been described by Stommel (1960) as a "narrow, intense, northeastward-flowing current which returns to the north against the southward driven Sargasso Sea water that has passed through the Caribbean and has turned through the Florida Straits. The Gulf Stream flows along the western boundary of the warm Sargasso Sea surface water. As the Stream turns toward the east, off the Grand Bank, it acts as a kind of dynamic barrier, or dam, which by virtue of Coriolis forces

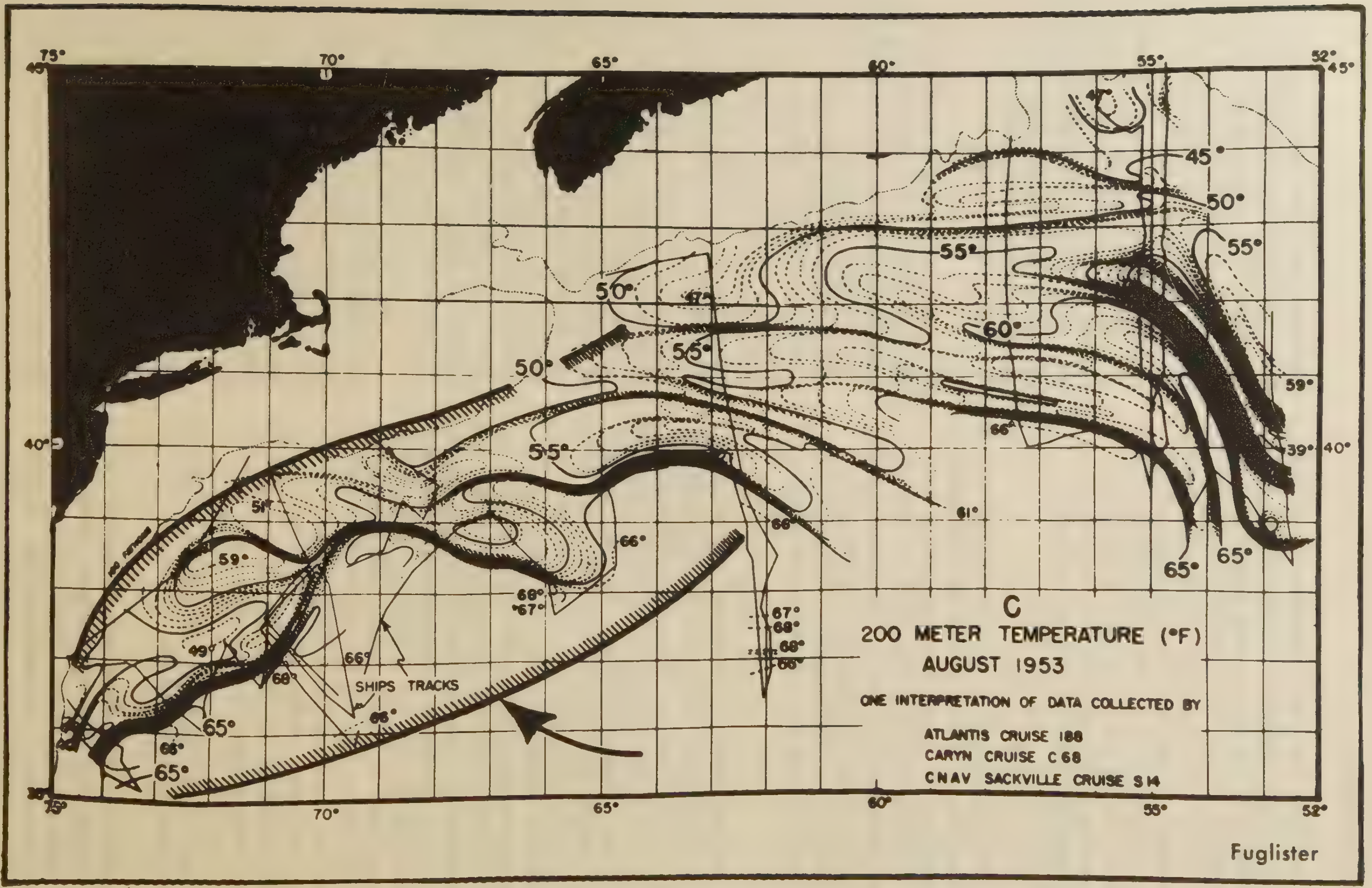
C
200 METER TEMPERATURE (°F)
AUGUST 1953
ONE INTERPRETATION OF DATA COLLECTED BY
ATLANTIS CRUISE 188
CARYN CRUISE C 68
CNAV SACKVILLE CRUISE S 14
SHIPS TRACKS
Fuglister
75°
70°
65°
60°
55°
52°
45°
40°
35°
45°
50°
55°
60°
65°
66°
67°
68°
59°
61°
49°
51°
39°

Fig. 1 Area of greatest exploratory fishing effort, outlined on chart by Fuglister and Worthington (1951), showing the multiple current hypotheses of the Gulf Stream System.

restrains the warm Sargasso water from overflowing the colder northern water of the North Atlantic".

The former concept that the Gulf Stream is one gradually widening and weakening current is not valid. Instead it is a series of overlapping, narrow, swift streaks or flows, effectively separating the warm, highly saline water to the south from the northern, cooler, less saline water. Detailed studies of the Gulf Stream reveal that it may have variations in its course in the form of pulsing or non-sinusoidal, wave-like perturbations of various amplitudes and frequencies, cyclonic eddies, both north and south of the stream and one or more areas of rapid current flow. The warm core of the Gulf Stream is reported to be 300 to 400 m deep, and water in the upper 200 m was found to be warmer than 20°C in June (Fuglister and Worthington 1951; Iselin 1960).

The meandering characteristic of the Stream forms after leaving Cape Hatteras, and Fuglister and Worthington report that by the time the Stream reaches longitude 70°W, but not before, waves large enough to form an eddy could develop. This phenomenon is in the area of exploration where excellent catches of bluefin tuna, Thunnus thynnus (Linnaeus), were made during the seasons of winter and spring. (Fig. 2)

Water masses in the Gulf Stream frontal area between the axis and the cooler waters of the north are not stable. Using a vessel and an airborne infra-red radiometer (von Arx, Bumpus and Richardson 1955) revealed that the frontal structure is composed of short, overlapping water mass segments, having a left hand orientation looking down the Gulf Stream. This complex multi-front system is reported to be composed of current filaments, distinguishable by a number of physical features extending to distances of up to 500 km. The frontal area is sometimes observable due to a color boundary or long lines of Sargassum weed on the surface. (Fig. 3)

The rapidly changing oceanographic characteristics of the Gulf Stream complicate the understanding of the relationship of the environment to the fish resources. However, in many cases, this dynamic action of two dissimilar water masses results in an abrupt temperature gradient occurring across the frontal area. During certain seasons of the year bluefin and yellowfin tunas may be effectively separated in their distribution over a very short geographical distance. Observations on species distribution have been noted in the Northwest Pacific by Japanese scientists (Nakamura 1951, 1956).

3 WATER TEMPERATURES IN RELATION TO TUNA DISTRIBUTION

Water temperatures in much of the area explored in the Northwest Atlantic are within the observed temperature range of several species of tuna, yet in many of these areas only an occasional tuna is taken. No doubt, environmental factors other than temperature influence the distribution and abundance of tunas, but results of exploratory fishing indicate that water temperature is one important environmental key to species distribution in the north frontal area of the Gulf Stream. To illustrate this general relationship, surface isotherms and 52.7 m isobathytherms taken from bathythermograph casts are given in Fig. 4 to 7, representing four of the first six exploratory cruises of the Delaware. The isobathytherms are representative of the approximate fishing depth. Fishing depth was determined by calculation of the mean hook depth, based on echograph observation of identical tuna longline gear as used by Bullis (1955).

Fig. 4 to 7 indicate only the dominant species at each station. Yellowfin tuna, Thunnus albacares (Bonnaterre), were often taken in association with albacore, Thunnus alalunga (Bonnaterre), particularly on stations having a small catch per unit effort. Bluefin tuna were sometimes taken in association with yellowfin tuna at stations near the Gulf Stream axis, and with albacore at stations north of the Gulf Stream axis.

Explorations during the spring (Fig. 4, cruise 57-3) illustrate the association of bluefin tuna with the warm waters close to the Gulf Stream axis. Cruise 58-2 (Fig. 5), conducted north of the Gulf Stream and southwest of the Grand Bank, shows the same general relationship to the Gulf Stream. Scattered

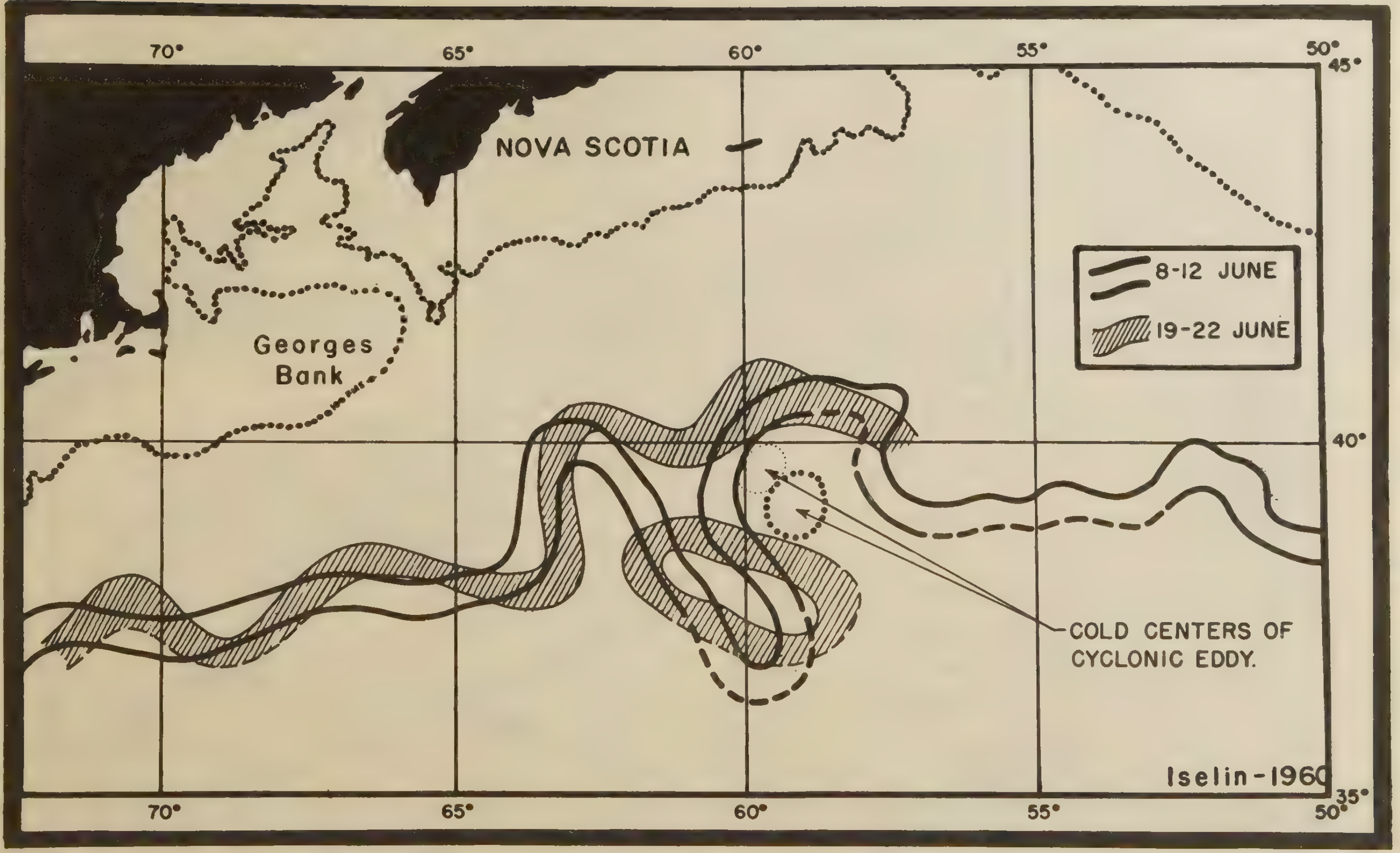
70°
65°
60°
55°
50°
45°
40°
35°
NOVA SCOTIA
Georges Bank
8-12 JUNE
19-22 JUNE
COLD CENTERS OF CYCLONIC EDDY.
Iselin-1960

Fig. 2 The "meandering" characteristic and cyclonic eddy formation of the Gulf Stream - from Iselin 1960.

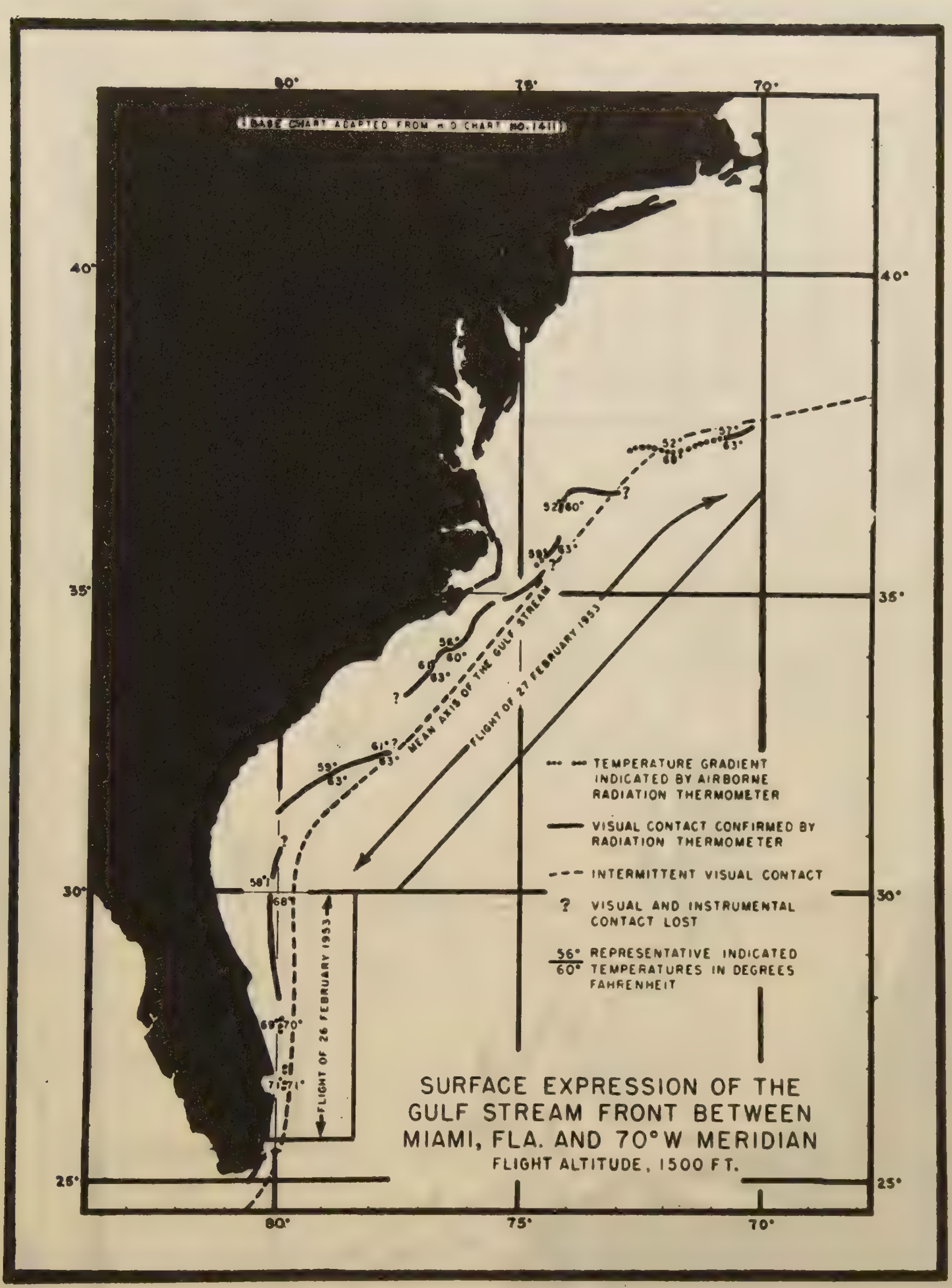
BASE CHART ADAPTED FROM H.O. CHART NO. 1411
80°
75°
70°
40°
35°
30°
25°
MEAN AXIS OF THE GULF STREAM
FLIGHT OF 27 FEBRUARY 1953
FLIGHT OF 26 FEBRUARY 1953
52°
57°
63°
68°
52°
60°
?
58°
63°
56°
60°
60°
63°
61°
59°
63°
58°
68°
69°
70°
71°
71°
TEMPERATURE GRADIENT INDICATED BY AIRBORNE RADIATION THERMOMETER
VISUAL CONTACT CONFIRMED BY RADIATION THERMOMETER
INTERMITTENT VISUAL CONTACT
? VISUAL AND INSTRUMENTAL CONTACT LOST
56° / 60° REPRESENTATIVE INDICATED TEMPERATURES IN DEGREES FAHRENHEIT
SURFACE EXPRESSION OF THE GULF STREAM FRONT BETWEEN MIAMI, FLA. AND 70°W MERIDIAN
FLIGHT ALTITUDE, 1500 FT.

Fig. 3 Surface expression of the Gulf Stream front, from von Arx, Bumpus, and Richardson (1955).

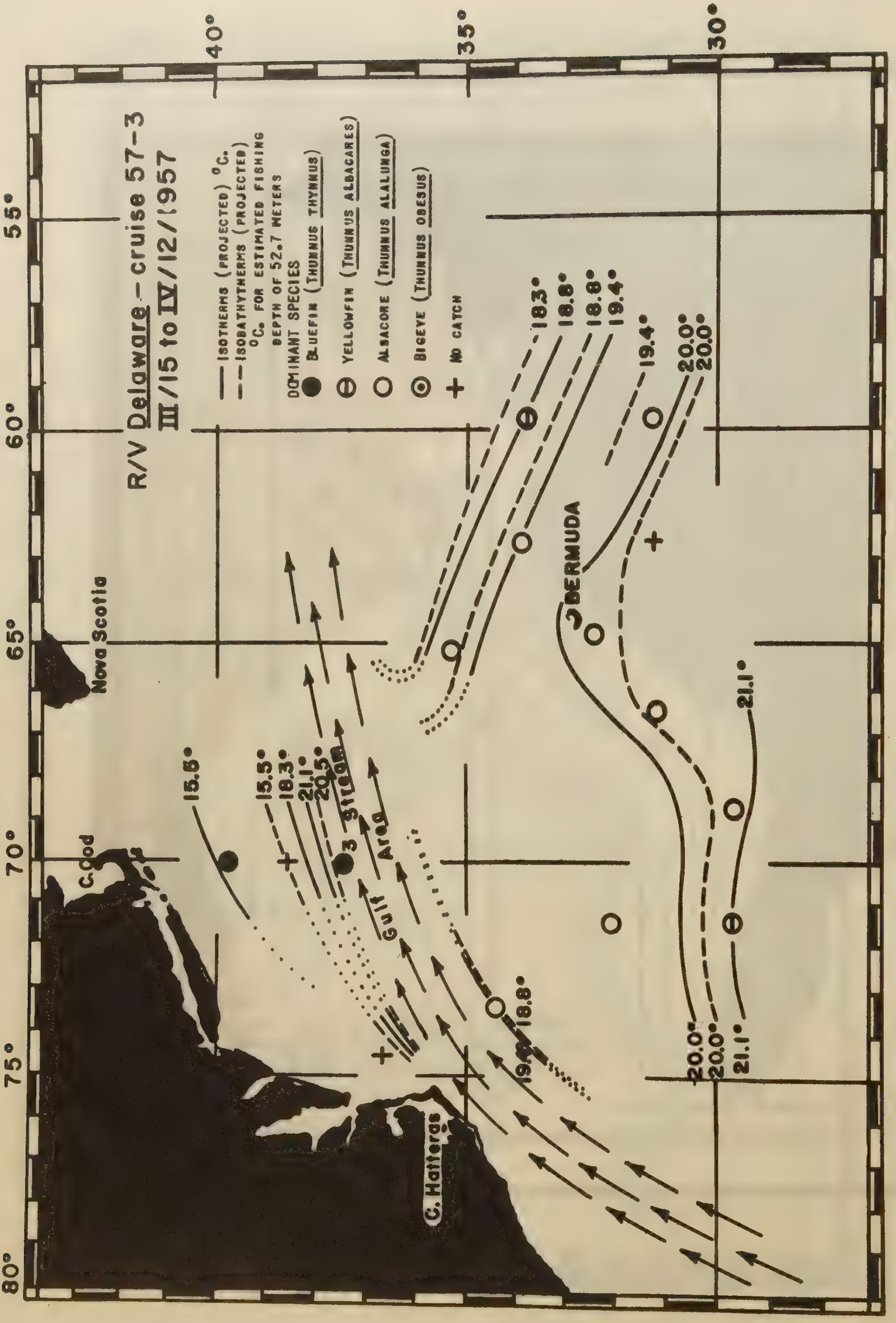
R/V Delaware – cruise 57-3
III/15 to IV/12/1957
— Isotherms (projected) °C.
– – Isobathytherms (projected) °C. for estimated fishing depth of 52.7 meters
Dominant species
● Bluefin (Thunnus thynnus)
⊖ Yellowfin (Thunnus albacares)
○ Albacore (Thunnus alalunga)
⊙ Bigeye (Thunnus obesus)
+ No catch
40°
35°
30°
55°
60°
65°
70°
75°
80°
Nova Scotia
C. Cod
C. Hatteras
BERMUDA
Gulf Stream Area
3
15.5°
15.5°
18.3°
21.1°
20.5°
18.3°
18.8°
18.8°
19.4°
19.4°
20.0°
20.0°
18.8°
19.4°
20.0°
20.0°
21.1°
21.1°

Fig. 4 Projected surface isotherms and 52.7 m isobathytherms for exploratory cruise 57-3 in relation to the dominant species at each fishing station.

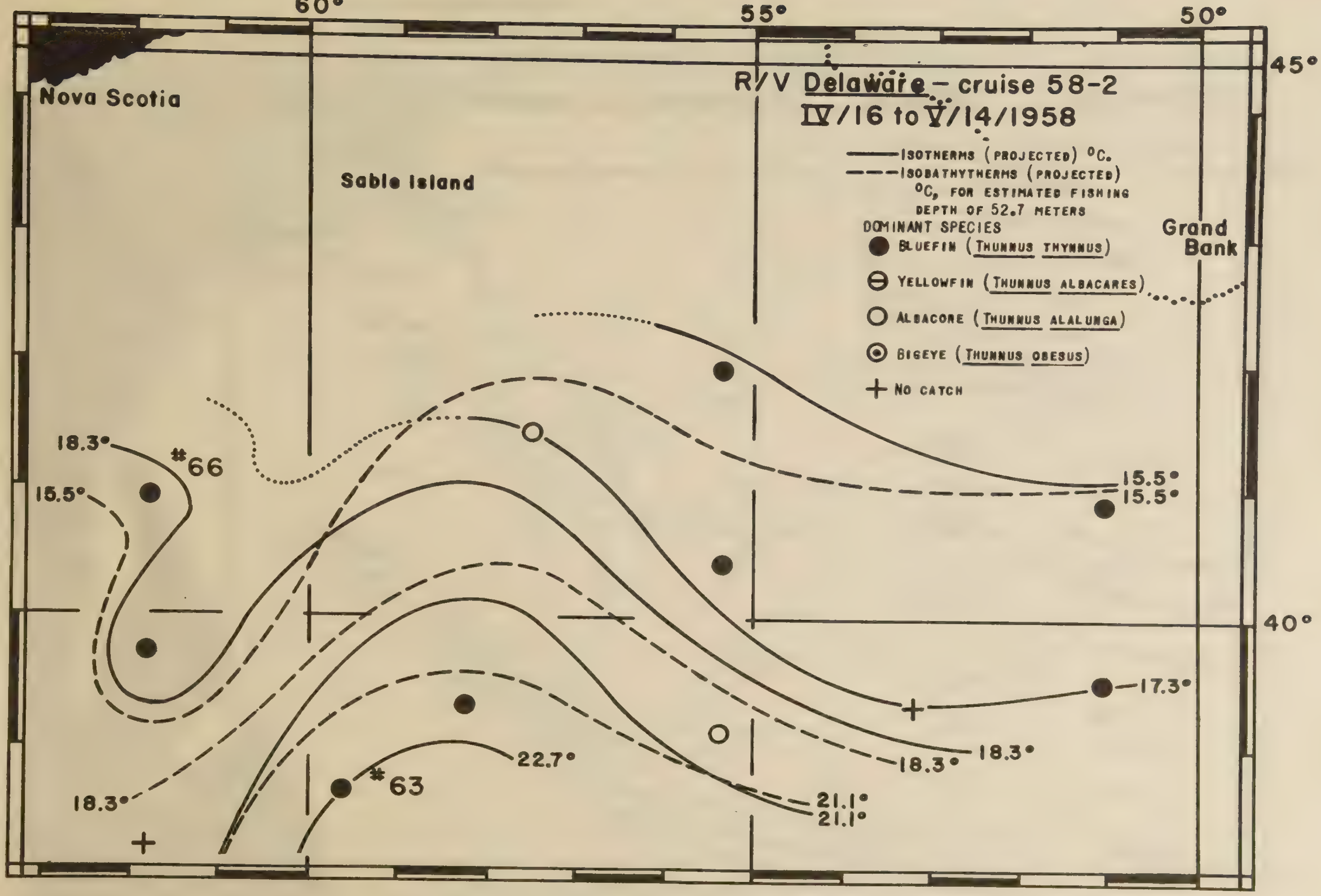
60°
55°
50°
45°
40°
Nova Scotia
Sable Island
Grand Bank
R/V Delaware – cruise 58-2
IV/16 to V/14/1958
—— Isotherms (projected) °C.
– – – Isobathytherms (projected) °C, for estimated fishing depth of 52.7 meters
Dominant species
● Bluefin (Thunnus thynnus)
⊖ Yellowfin (Thunnus albacares)
○ Albacore (Thunnus alalunga)
⊙ Bigeye (Thunnus obesus)
+ No catch
18.3°
15.5°
#66
15.5°
15.5°
17.3°
18.3°
18.3°
21.1°
21.1°
22.7°
#63
18.3°

Fig. 5 Projected surface isotherms and 52.7 m isobathytherms for exploratory cruise 58-2 in relation to the dominant species at each fishing station.

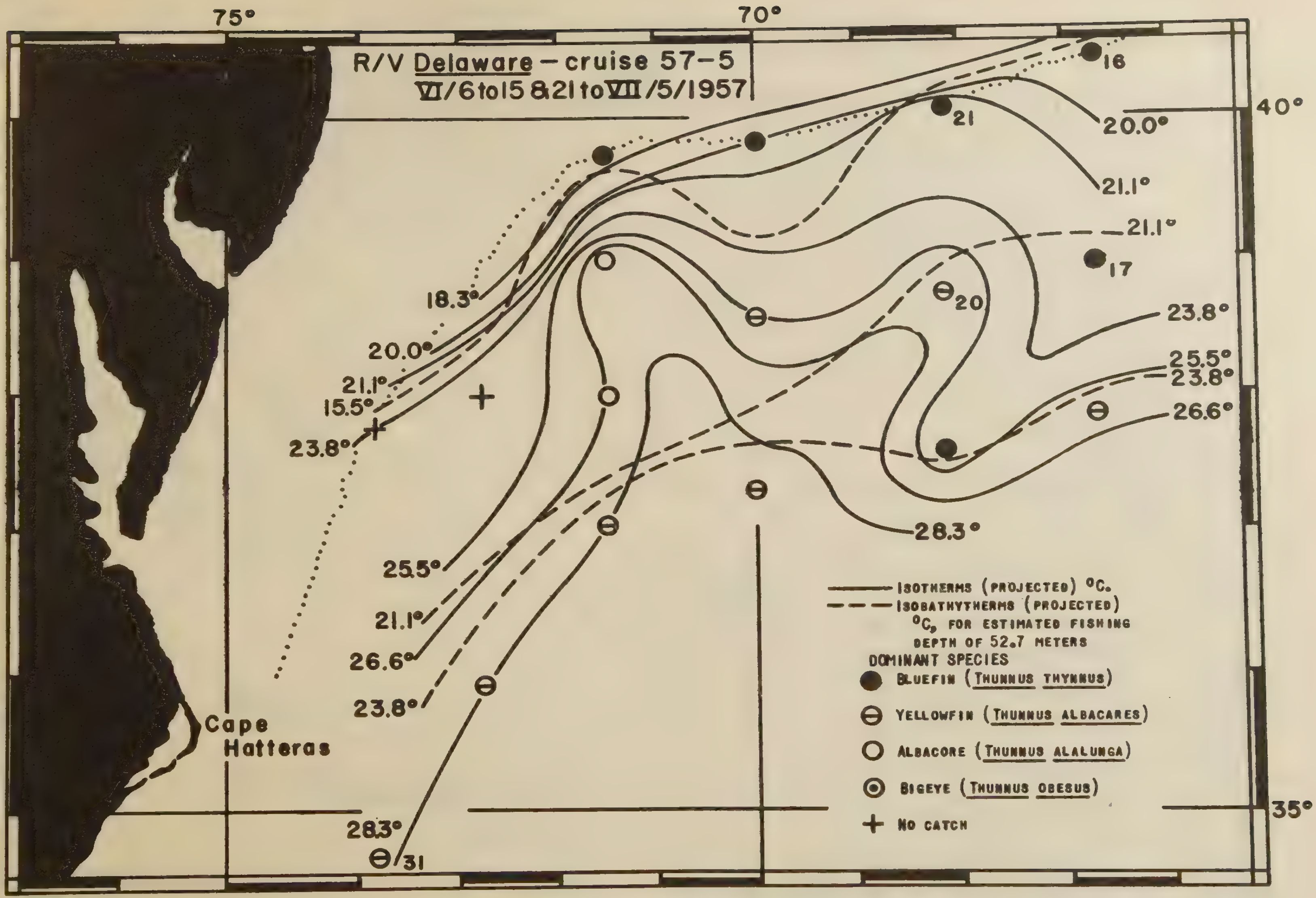
75°
70°
40°
35°
R/V Delaware – cruise 57–5
VI/6 to 15 & 21 to VII/5/1957
16
21
17
20
31
20.0°
21.1°
21.1°
23.8°
25.5°
23.8°
26.6°
28.3°
18.3°
20.0°
21.1°
15.5°
23.8°
25.5°
21.1°
26.6°
23.8°
28.3°
Cape Hatteras
Isotherms (projected) °C.
Isobathytherms (projected) °C, for estimated fishing depth of 52.7 meters
Dominant species
Bluefin (Thunnus thynnus)
Yellowfin (Thunnus albacares)
Albacore (Thunnus alalunga)
Bigeye (Thunnus obesus)
No catch

Fig. 6 Projected surface isotherms and 52.7 m isobathytherms for exploratory cruise 57-5 in relation to the dominant species at each fishing station.

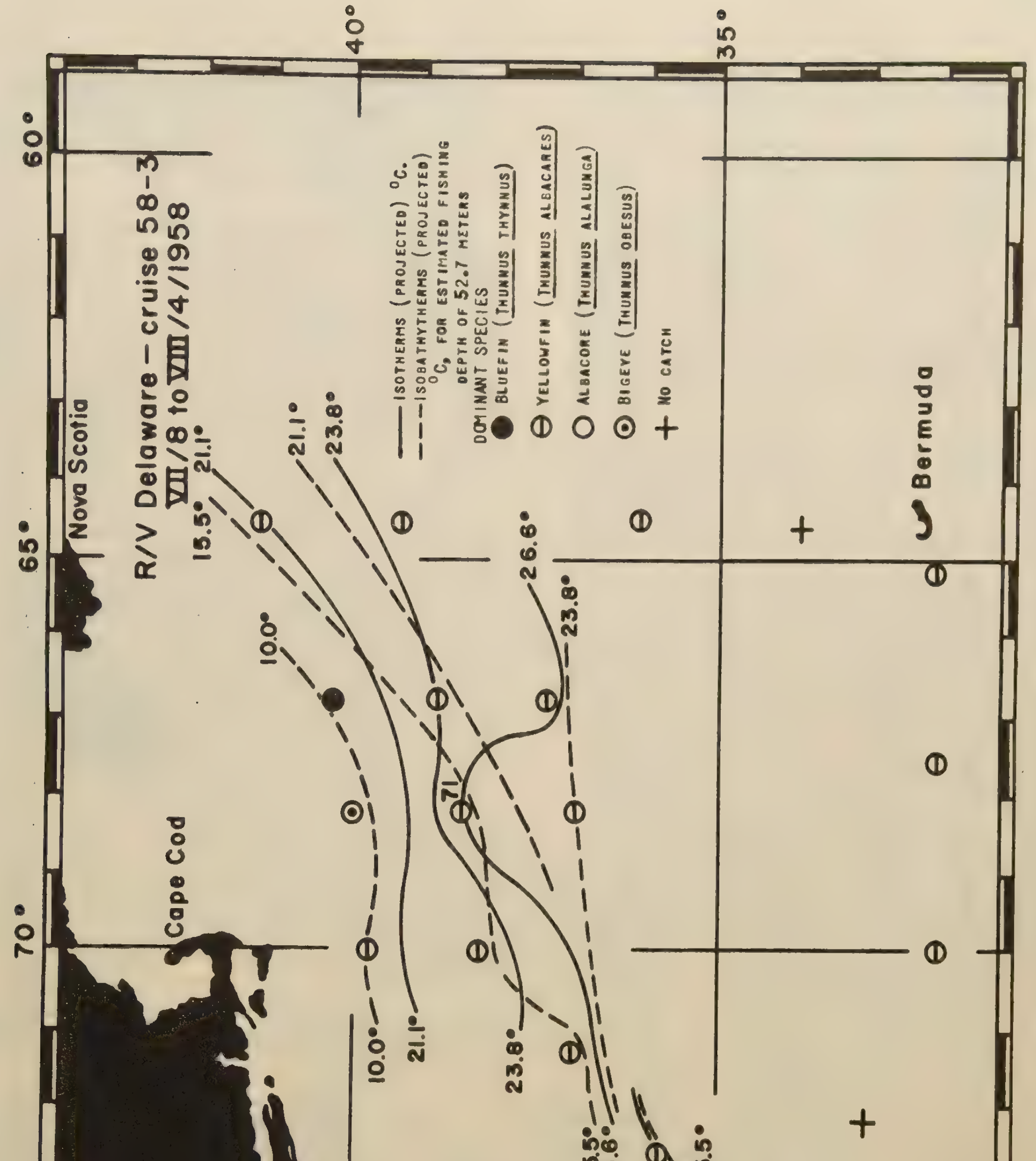
R/V Delaware – cruise 58-3
VII/8 to VIII/4/1958
—— Isotherms (projected) °C.
– – – Isobathytherms (projected) °C, for estimated fishing depth of 52.7 meters
Dominant species
● Bluefin (Thunnus thynnus)
⊖ Yellowfin (Thunnus albacares)
○ Albacore (Thunnus alalunga)
⊙ Bigeye (Thunnus obesus)
+ No catch
Nova Scotia
Cape Cod
Cape Hatteras
Bermuda
60°
65°
70°
75°
40°
35°
10.0°
15.5°
21.1°
23.8°
26.6°
25.5°
28.3°

Fig. 7 Projected surface isotherms and 52.7 m isobathytherms for exploratory cruise 58-3 in relation to the dominant species at each fishing station.

catches of yellowfin tuna and albacore were taken during cruise 57-3 in the area south of the Gulf Stream. Temperatures at 52.7 m were lower over this large area than they were at the station on the northern edge of the Gulf Stream. Projected isotherms and isobathytherms for cruise 58-2 indicate the formation of a "loop-sack" structure as described by Uda (1960). Catch per unit of effort was high at stations 63 and 66. In the case of station 66 this hydrographic feature could have resulted in the concentration of tuna.

The area north of the Gulf Stream axis from longitude 72° W to southeast of the Grand Bank appears to be productive for bluefin tuna, generally in surface water temperature of 18° to 22° C± during the winter and spring seasons. A shift in species composition occurs during early summer, when yellowfin tuna becomes the dominant species in and north of the Gulf Stream. Water temperatures warm to 21° to 27° C range during this period.

Fig. 6 (cruise 57-5) during late spring and early summer illustrates the transition period from a bluefin tuna to a yellowfin tuna dominance. Isotherms show protrusions of warm water into the higher latitudes. Isobathytherms show less change, as expected. Excellent catch per unit effort was recorded for bluefin tuna at stations 16 and 17 and 21 and for yellowfin tuna at station 20 - an area of compressed isotherms.

During the summer (Fig. 7) the temperature structure for cruise 58-3 shows no marked change, but yellowfin tuna assumed dominance in the area north of the Gulf Stream axis, and catches of 2 to 5.6 fish per 100 hooks were obtained at several stations.

The center of bluefin tuna abundance shifts from the oceanic area to the continental shelf in early summer and is common to this area until fall. Temperature data indicate that bluefin tuna in the oceanic area are common in water of 15.5° C at the estimated fishing depth of 52.7 m. Mean surface temperatures during the summer months in the inshore areas ranged from 12.0° C to 17.8° C at the Boston Light Vessel during the period June to October 1957 (Day 1959). This suggests that bluefin tuna experience only moderate change in water temperature in their migration from the Gulf Stream System to the continental shelf area in the summer.

Data from previous cruises led to a hypothesis on the distribution of bluefin tuna during the spring. Cruises 59-6 and 60-6, the final two of the series, were designed to explore an area where bluefin tuna were estimated to be abundant in the spring (59-6) and to investigate the Gulf Stream area off Cape Hatteras for yellowfin tuna in the spring (60-6).

After sizable concentrations of bluefin tuna were intercepted at stations 97, 98 and 99 (Fig. 8), the cruise plan was altered to investigate the water temperature and geographical relationship of yellowfin tuna and bluefin tuna. Station 100, 40 km due south of station 99, yielded no bluefin tuna but many yellowfin tuna. The surface temperature increase between station 99 and 100 was 7.2°C.

Cruise 60-6 illustrates this same temperature-geographical relationship. Yellowfin tuna were taken at a high rate of yield (14.1 fish per 100 hooks) at station 106 near the Gulf Stream axis northeast of Cape Hatteras. The next inshore station, 84 km away and 12.6° C cooler at the surface, yielded only bluefin tuna.

4 CATCH TEMPERATURE RANGES AND MEANS

Mean catch temperatures, both at the surface and at the estimated fishing depth, were calculated for each tuna species taken during Delaware explorations. Examination of the means and the catches shows that the tunas may be ranked according to temperature preferences, from coolest to warmest; bluefin, albacore, bigeye and yellowfin.

Calculations were made using the formula $\bar{x} = \frac{\Sigma(f \times t)}{N}$; f = the number of a species in a sample where the sample is the catch at a single station; t = water temperature in degrees C, and N = the total number of a species for which data are available.

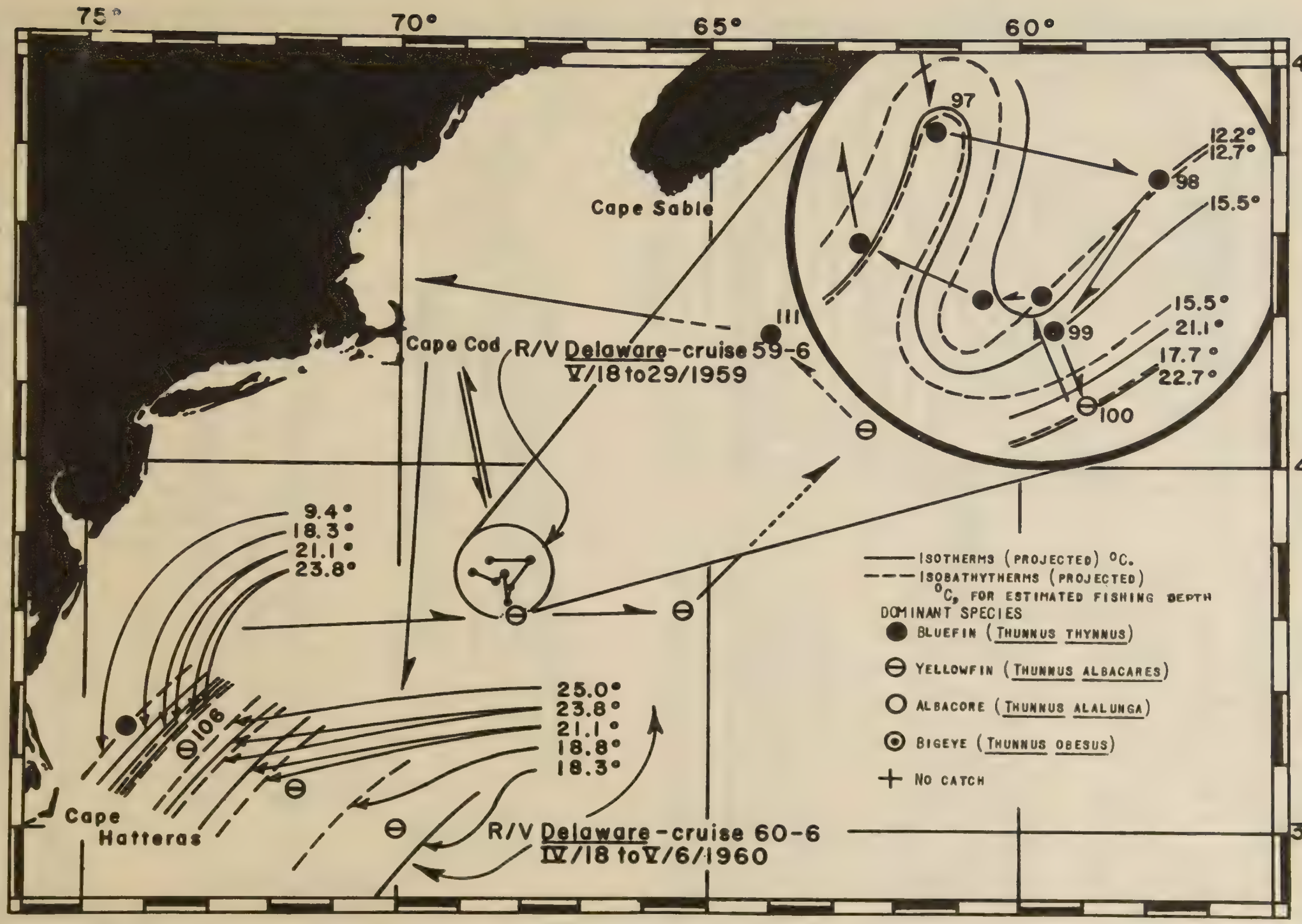
75°
70°
65°
60°
45°
40°
35°
Cape Sable
Cape Cod
Cape Hatteras
R/V Delaware-cruise 59-6
V/18 to 29/1959
R/V Delaware-cruise 60-6
IV/18 to V/6/1960
97
98
99
100
106
111
12.2°
12.7°
15.5°
15.5°
21.1°
17.7°
22.7°
9.4°
18.3°
21.1°
23.8°
25.0°
23.8°
21.1°
18.8°
18.3°
ISOTHERMS (PROJECTED) °C.
ISOBATHYTHERMS (PROJECTED) °C, FOR ESTIMATED FISHING DEPTH
DOMINANT SPECIES
● BLUEFIN (THUNNUS THYNNUS)
⊖ YELLOWFIN (THUNNUS ALBACARES)
○ ALBACORE (THUNNUS ALALUNGA)
⊙ BIGEYE (THUNNUS OBESUS)
+ NO CATCH

Fig. 8 Projected surface isotherms and 52.7 m isobathytherms for exploratory cruises 59-6 and 60-6 showing the close geographic separation of two major species in relation to observed water temperatures.

Standard deviation of the mean was computed for both surface and estimated fishing depth, using the formula $\sigma = \sqrt{\frac{\Sigma(x - \bar{x})^2}{N - 1}}$, where x = either surface or estimated fishing depth temperature; $\bar{x}$ = mean temperature at surface or estimated fishing depth; N = total number of fish.

Observed temperature ranges and calculated means for tuna species taken during explorations are given in Table I. Distribution of bluefin tuna, yellowfin tuna and albacore catches in relation to observed temperatures at the estimated fishing depth (52.7 m) are given in Table II.

Water temperatures at the estimated fishing depth ranged from 6.55° C (43.8° F) to 26.95° C (80.5° F). Bluefin tuna and yellowfin tuna were taken at the estimated fishing depth from stations having the warmest water temperature, and bluefin tuna was taken from the station having the coolest water temperature.

The temperature ranges of three tuna species common to the oceanic Northwest Atlantic are shown graphically in Fig. 9. In addition, ranges for bluefin tuna, albacore and yellowfin tuna have been abstracted from a diagram illustrating the "optimum water temperature spectra of important fishes in Japan", prepared by Uda (1957). Comparison of temperatures indicates a close similarity between the midpoint of Uda's optimum temperature to the calculated mean catch temperature for bluefin tuna and yellowfin tuna. In Uda's graph the temperature ranges are small when compared with data from the oceanic Northwest Atlantic. If Uda's data were obtained from the commercial fishery, this could account for the difference. The commercial fishery attempts to operate in areas of maximum abundance, and this tends to restrict observed water temperature ranges. The Delaware exploratory survey covered a large area having a wide sample of observed water temperatures with only one attempt being made to continue production fishing in an area of abundance.

Table I

Catch Temperature Ranges (°C) and Means (°C)

	At the Surface	$\bar{x}$	At the Estimated Fishing Depth	Difference (low to high)	$\bar{x}$
Bluefin tuna N=871 (Surface) N=854 (Est. fish. depth)	6.4° to 28.8°	16.2°	6.5° to 26.9°	20.4°	15.5°
Albacore N=110	11.5° to 28.3°	20.8°	8.7° to 26.7°	18.0°	17.5°
Yellowfin tuna N=636 (Surface) N=613 (Est. fish. depth)	18.4° to 28.8°	25.2°	10.0° to 26.9°	16.9°	22.2°
Bigeye (N=31)	13.5° to 27.3°	18.7°	8.7° to 26.9°	18.2°	13.3°
Skipjack (N=7)	21.5° to 26.7°	25.3°	19.4° to 26.4°	7.0°	23.6°

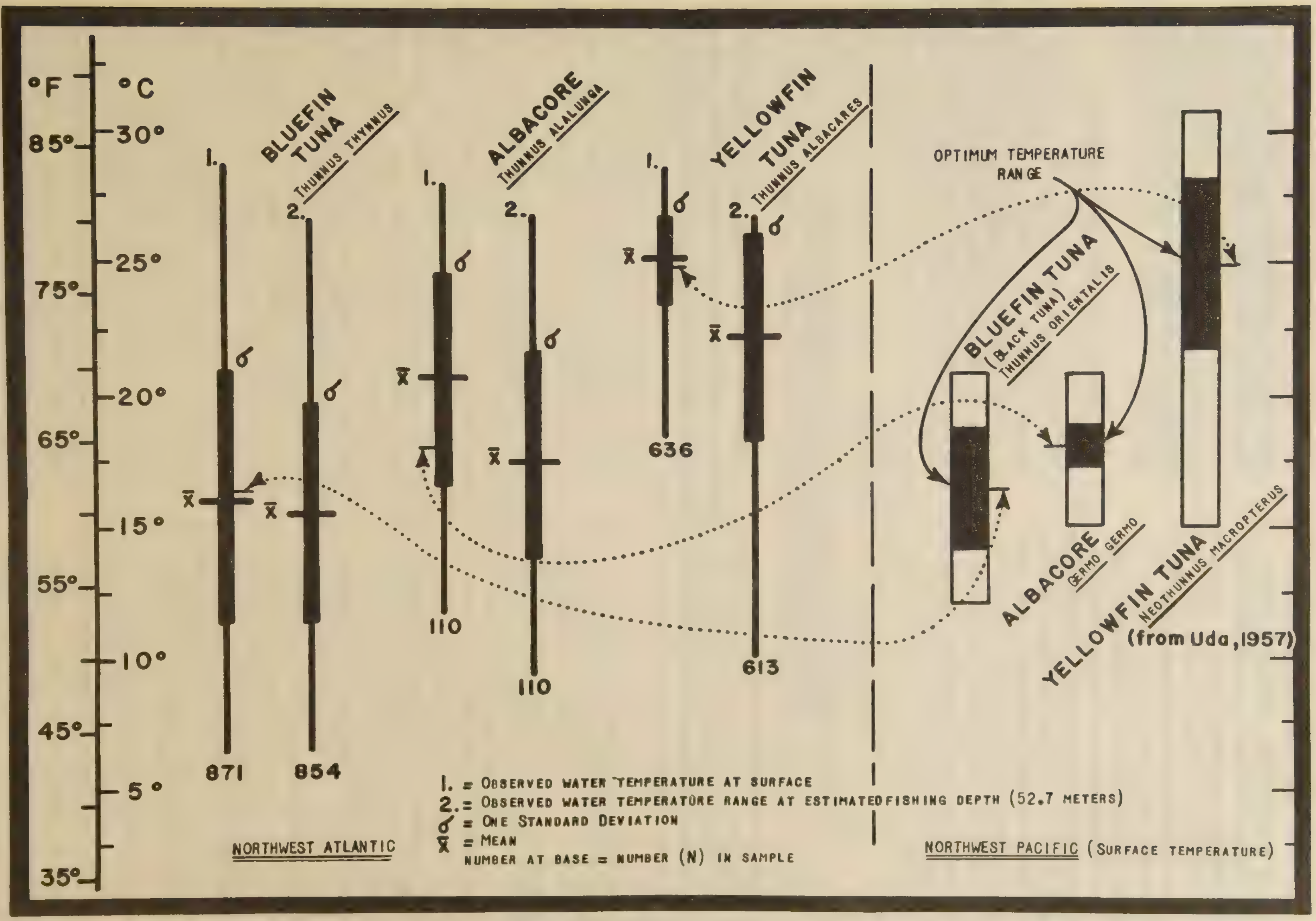

Fig. 9 Observed water temperature ranges of tuna species in the oceanic northwest Atlantic and the optimum temperature spectra of three tuna species in the northwest Pacific as developed by Uda (1957).

In Fig. 9 temperature deviations from the mean for yellowfin tuna are greater for observations at the estimated fishing depth than at the surface. Yellowfin tuna are apparently more closely associated with surface temperatures than with temperatures at the estimated fishing depth. Deviations from the mean for bluefin tuna are slightly less for temperature observations at the estimated fishing depth than at the surface, indicating a closer association of this species to the estimated fishing depth.

Surface temperatures, at which yellowfin tuna were taken in the eastern Pacific, were recorded by Blunt and Messersmith (1960). From their data, the mean surface catch temperature was calculated to be 21.9° C, closely comparable to the calculated mean of 22.3° C, for 52.7 m depth in the Atlantic.

5 SUMMARY AND DISCUSSION

In many areas in the tropical and temperate seas of the world there are accumulations of biota which appear to be the result of optimum environmental conditions. These areas within the ocean are sometimes associated

Table II

Catch Distribution in Relation to the Temperature Range at the Estimated Fishing Depth (52.7 m).

°F/°C	Number of Stations	Bluefin # of Stations	 # of Fish	Yellowfin # of Stations	 # of Fish	Albacore # of Stations	 # of Fish
43.8°/6.55° to 44.9°/7.17°	2	2	75				
45.0°/7.22° to 49.9°/9.94°	2	2	5			1	5
50.0°/10.00° to 54.9°/12.72°	4	2	19	2	11	3	7
55.0°/12.78° to 59.9°/15.52°	23	12	431	6	55	11	28
60.0°/15.56 to 64.9°/18.28°	13	6	125	6	81	8	21
65.0°/18.33° to 69.9°/21.06°	23	7	59	13	55	16	34
70.0°/21.11° to 74.9°/23.83°	16	5	132	13	110	7	9
75.0°/23.89° to 79.9°/26.61°	18	3	5	16	240	3	4
80.0°/26.67° to 80.5°/26.95°	4	3	3	4	61	2	2

with convergence zones and other ocean current phenomena.

Explorations for tuna, from 1957 to 1960, resulted in an increase in knowledge of the pelagic tuna resources in the oceanic Northwest Atlantic. Detailed studies of the Gulf Stream System by the Woods Hole Oceanographic Institution have resulted in a better interpretation of the results of exploratory fishing.

Oceanic water temperatures, where tuna occur, have been the subject of investigation for a number of years, and knowledge of these parameters has been useful in the development of tuna forecasts for the commercial fisheries. In the oceanic Northwest Atlantic, temperature data taken by bathythermograph casts at each exploratory station were examined for surface water temperature and temperature at an estimated fishing depth of 52.7 m. Catch temperature means, calculated for each species, indicate significant differences in optimal ranges among species.

Isotherms and isobathytherms were drawn for several cruises and illustrate geographical and temperature relationships of tuna species. Concentrations of the species common to cooler waters (bluefin tuna), and to species common to the tropical zone (yellowfin tuna), were found in proximity when fishing along the north frontal area of the Gulf Stream.

The major hydrobiological feature of the area explored is the Gulf Stream System. This current can be described as a northward extension of the environment of the North Equatorial Current. Water temperatures within the Gulf Stream core are tropical during the summer, reaching an observed surface temperature of 28.8° C. This is considerably above the mean catch temperature calculated for yellowfin tuna, a species normally associated with the equatorial zone. The hydrographic character of the Gulf Stream with its well developed convergence zone, cyclonic eddies and fluctuating wave structure is conducive to concentrations of tuna resources.

In comparison, for the Northwest Pacific, Uda (1959) reports that the best fishing areas for bluefin tuna are found in temperatures of 18° to 20° C where the Kuroshio and cold coastal waters meet, and that these areas are located where convergence of the frontal zone is maximal. The convergence zone of the Gulf Stream, a current analogous to the Kuroshio, is more pronounced in the surface area from off Cape Hatteras to longitude 70° and can be followed for considerable distances beyond the 70th meridian. It is within this general area and about the catch temperature mean of 15.5° C at the estimated fishing depth that excellent catches of bluefin tuna were made during the winter and spring.

Water temperatures rise during early summer, and hydrobiological conditions within the general area of the Gulf Stream continue to be suitable for tuna, but of the yellowfin species. At 52.7 m the observed water temperature mean calculated for all yellowfin tuna taken during the exploration was 22.2° C.

From isotherms and isobathytherms shown in Fig. 4 to 7, indications are that some stations could have been located in an area having a compression of isotherms. Some fishing stations located within these areas had a significantly higher catch per unit of effort. Increased catches might be expected with the concentrations of iostherms in protrusions or ultimately into eddy currents, and research by the Japanese Fisheries Agency indicates that albacore were found in sacklike, warm, eddy currents of the Western Pacific.

Observed water temperatures for the major species taken during oceanic North Atlantic explorations ranged over a considerably wider temperature spectrum than those presented by Uda (1959) for the important commercial fishes in Japan for reasons given earlier. The observed range of temperature for each of the major species in the Atlantic at 52.7 m was: bluefin tuna --20.4° C, bigeye tuna--18.2° C, albacore --18.0° C, and yellowfin tuna --16.9° C. Uda's optimum temperature spectra for these fishes in Japan give ranges for: bluefin tuna--10.0° C, bigeye tuna--17.0° C, albacore--7.8° C, and yellowfin tuna--15.8° C. From observations over a broad area of the western North Atlantic it appears that the major species tolerate considerable temperature ranges, with yellowfin tuna having the least observable range.

Temperature was found to be an important measurable factor in determining the distribution and abundance of tunas in the Gulf Stream System. A detailed study of this System, combining exploratory fishing with rapid, synoptic temperature measurements, promises to provide a valuable method for identification of productive tuna fishing areas.

Experience Paper No. 39

FOOD OF INDIAN TUNAS

By

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Abstract

The existing knowledge on the food of Indian tunas is only of a preliminary nature and relates to the following species: Auxis thazard, Auxis thynnoides, Euthynnus affinis affinis, Sarda orientalis, Kishinoella tonggol, Katsuwonus pelamis and Neothunnus macropterus. This has been briefly reviewed and compared with observations from other areas.

ALIMENTS DES THONS INDIENS

Résumé

Nos conaissances actuelles sur l'alimentation des thons indiens en sont encore à une étape préliminaire et concernent les espèces suivantes: Auxis thazard, Auxis thynnoides, Euthynnus affinis affinis, Sarda orientalis, Kishinoella tonggol, Katsuwonus pelamis et Neothunnus macropterus.

L'article traite brièvement de ces questions et compare les résultats avec les observations recueillies dans d'autres zones.

EL ALIMENTO DE LOS ATUNES DE LA INDIA

Extracto

Los conocimientos existentes del alimento que consumen los atunes de la India son tan sólo de naturaleza preliminar y se refieren a las siguientes especies: Auxis thazard, Auxis thynnoides, Euthynnus affinis affinis, Sarda orientalis, Kishinoella tonggol, Katsuwonus pelamis y Neothunnus macropterus. Se han hecho reseñas breves y comparaciones con observaciones de otras aguas.

1 INTRODUCTION

Investigations on the food and feeding habits and various other aspects of the biology of Indian tunas have been initiated only recently. Preliminary observations from Indian waters are available on the food of the frigate mackerels Auxis thazard (Lacépède) and Auxis thynnoides Bleeker, the little tunny Euthynnus affinis affinis (Cantor), the oriental bonito Sarda orientalis (Temminck and Schlegel), the oceanic skipjack Katsuwonus pelamis (Linnaeus), the northern bluefin tuna Kishinoella tonggol (Bleeker) and the yellowfin tuna Neothunnus macropterus (Temminck and Schlegel). Considerable work has been done in this field in other parts of the Indo-Pacific, especially on the oceanic skipjack and yellowfin tuna. The literature available is extensive. This paper attempts to bring together all the information available on the food of these species from Indian waters. An exhaustive discussion on the topic has not been attempted. A great deal of information has also accumulated in recent years on the bait fishes used in the tuna fishery in various parts of the Pacific ocean, the variability of response of tunas to bait fishes and similar aspects. In India, preliminary studies have been made on the tuna bait fish resources of the Laccadives and further work is in progress. In the present study, only the natural food of tunas has been considered.

2 THE LONG CORSELETTED FRIGATE MACKEREL Auxis thynnoides BLEEKER

The species was first recorded from Indian waters by Jones (1958a). It is caught, with A. thazard, from Malpe to Colachel on the west coast.

The food of this species, obtained by shore seines and boat seines at Vizhingam, an important tuna fishing center on the west coast, has been studied (Kumaran, 1962). The composition by volume of the various food items is given in Fig. 1. Fish ranged in size from 170 to 252 mm. Squids were the major food element by volume. Fish were next in importance, followed by crustaceans in small proportions. Species of Sardinella, Anchoviella and Leiognathus were represented in the food of the species.

The only other information available on the food of the species is from Japanese waters. A. thynnoides (= A. tapeinosoma) caught by pole and line in Japanese waters from December 1958 to April 1961, were observed to have fed on Scomber tapeinocephalus, Trachurus japonicus, Acinacea notha, Gonorhynchus abbreviatus, Elephenor macropus, Macrorhamphosus scolopax, Apogonichthys carinatus, Gnathagnus elongatus, lizard fishes, anchovy and cephalopods. Those caught by set nets had Scomber tapeinocephalus, Trachurus japonicus and lizard fishes as the major food items (Yokota et al., 1961).

3 THE SHORT CORSELETTED FRIGATE MACKEREL Auxis thazard (LACEPEDE)

Juveniles of A. thazard ranging in size from 49 to 132 mm were examined for food (Kumaran, 1962). They were also obtained by shore seines and boat seines at Vizhingam. Those from 49 to 75 mm had fish as the major item, followed by crustaceans, while fish and crustaceans were found in almost equal proportions in the larger size group (Fig. 1).

Tester and Nakamura (1957) observed that megalopa, stomatopod larvae and anomura larvae formed the food of the species from Oahu, Hawaii.

The food of A. thazard caught by trolling lines in Japanese waters during June 1959 consisted of skipjack, frigate mackerel, jack mackerel, flying fishes, file fishes, Mene maculata, Spratelloides japonicus, anchovy and squids (Yokota et al., 1961).

4 THE OCEANIC SKIPJACK Katsuwonus pelamis (LINNAEUS)

Studies on the food of the oceanic skipjack from Minicoy, the southernmost island of the Laccadive Archipelago during 1958 and 1959 have been made by Raju (1962) and for the season 1960-61 by Thomas (1962a). An important fishery for the species exists in Minicoy and the only gear employed is the pole and line, using live-bait fishes (Jones, 1958b; Jones and Kumaran, 1959). The fish studied ranged from 280 to 720 mm in length. Crustaceans (53.3 percent), fish (23 percent) and cephalopods (18 percent) were reported as the major items during 1958 and 1959 (Fig. 2). However, during the 1960/61 fishing season, fish (58.8 percent) and crustaceans (37.1 percent) were the major elements, while cephalopods formed only an insignificant item (Fig. 3). The fishes belonged to the families Exocoetidae, Dactylopteridae, Syngnathidae, Balistidae, Monacanthidae, Carangidae, Gempylidae, Ostraciontidae, Apogonidae, Dussumieriidae and Pomacentridae. The crustaceans were mainly represented by stomatopod larvae, megalopa, mysids and Acetes indicus.

Variations in the volume of food in relation to fish size were studied by Raju (1962). It was found that there was increase in food volume with increase in length and decrease in stomach content per unit of body weight with increase in weight. During both the periods of observation it was found that smaller fish fed mainly on crustaceans and, to a smaller extent, on fishes. Larger size groups of the skipjack had fish as the major item of food and crustaceans were next in importance. Fish above 700 mm had cephalopods as the principal item, followed by fishes. Thus it is seen that the importance of crustaceans as food increases in smaller skipjack size groups.

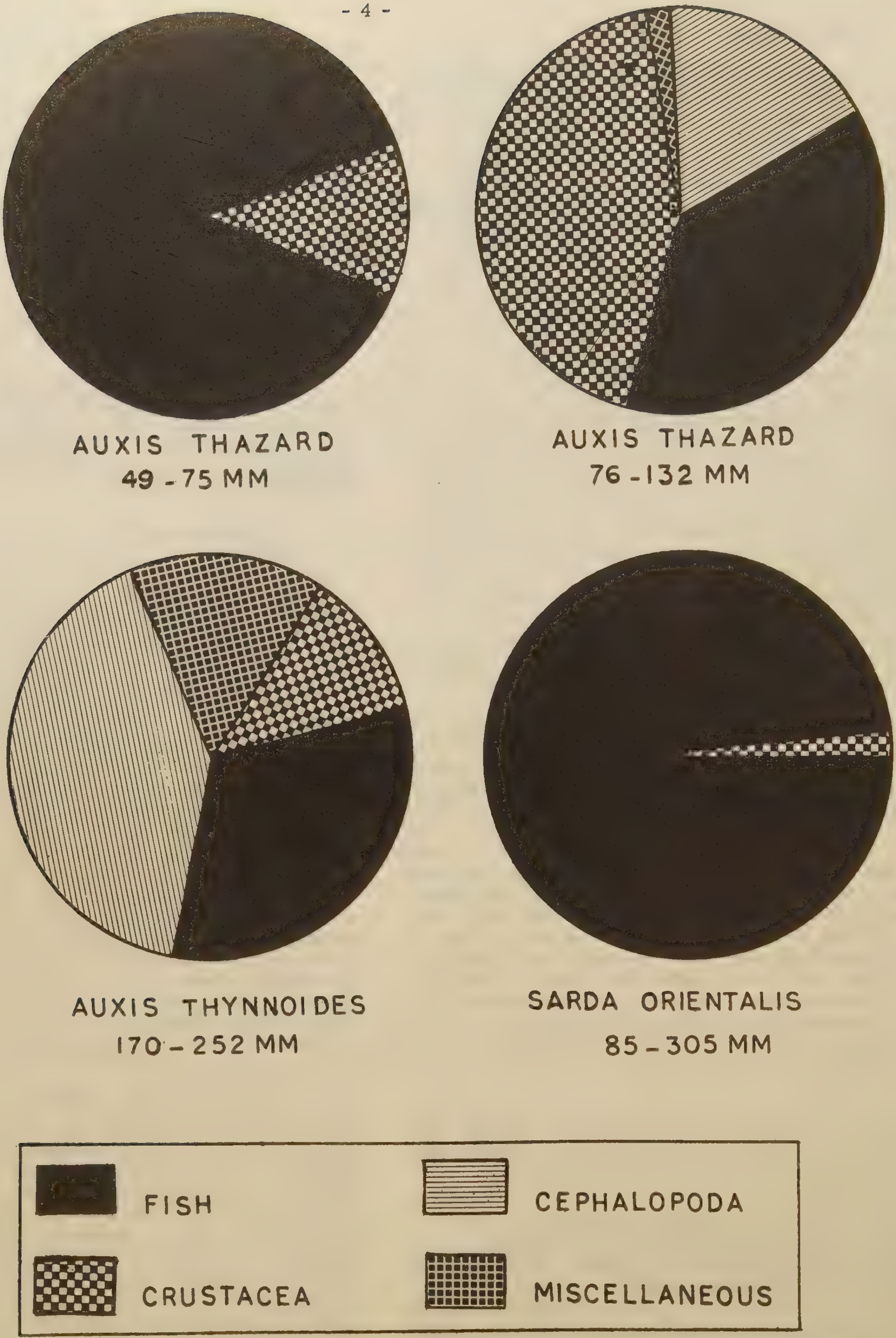


Fig.1. Diagrams illustrating the composition by volume of the stomach contents of Auxis thazard, A. thynnoides and Sarda orientalis

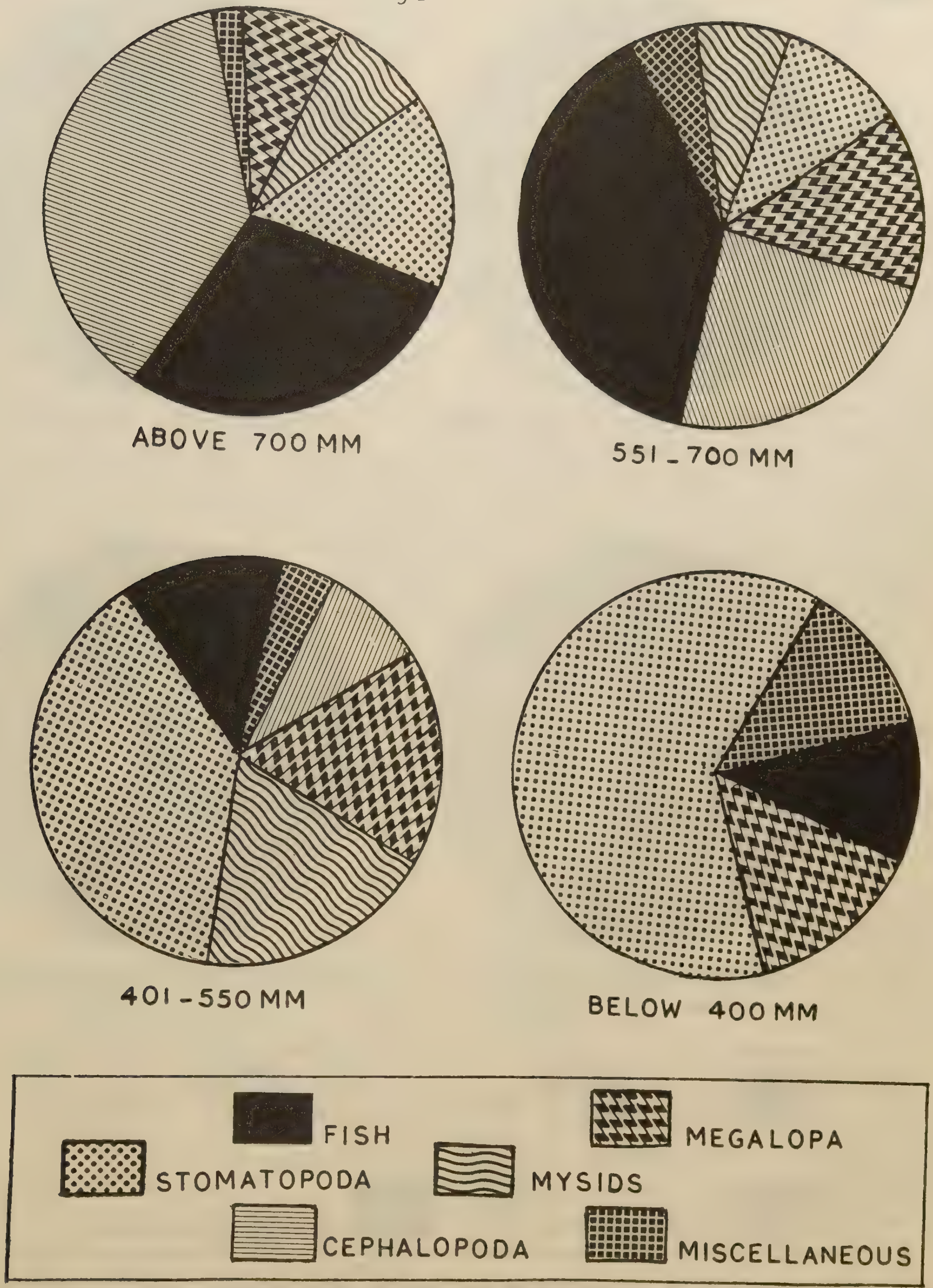
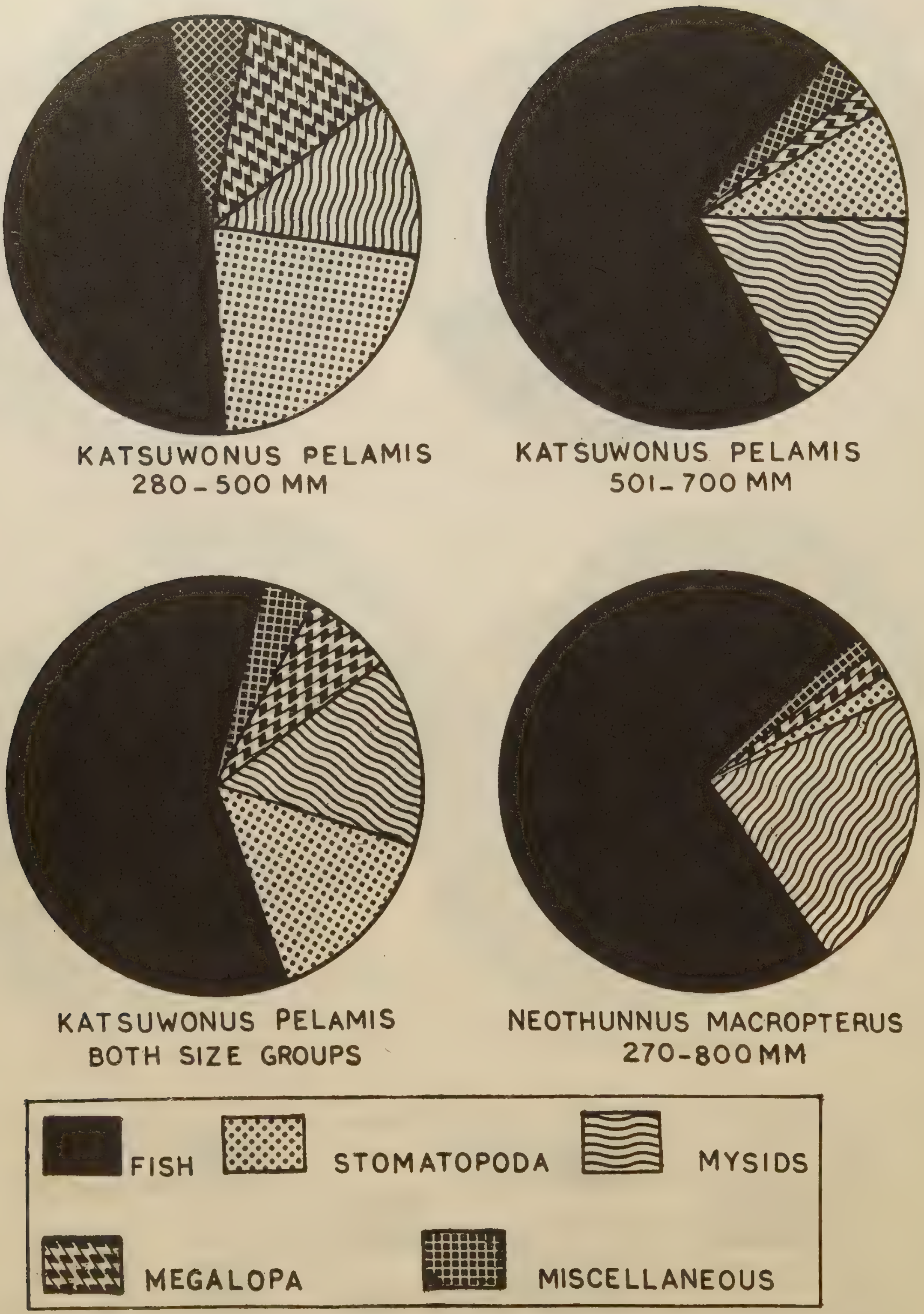


Fig.2. Diagrams illustrating the composition by volume of the stomach contents of Katsuwonus pelamis from Minicoy Island during the period 1958-59 (after Raju, 1962)



KATSUWONUS PELAMIS 280-500 MM

KATSUWONUS PELAMIS 501-700 MM

KATSUWONUS PELAMIS BOTH SIZE GROUPS

NEOTHUNNUS MACROPTERUS 270-800 MM

Fig.3. Diagrams illustrating the composition by volume of the stomach contents of *Katsuwonus pelamis* and *Neothunnus macropterus* from Minicoy during the season 1960-61 (after Thomas, 1962)

They are not represented in the food of the largest size group. The percentage of fish with empty stomachs was very high during both periods. In fish containing food, the food volume was very low -- in a high percentage, measuring below one cc. This may be because they are drawn from large surface shoals.

Studies have been made on bait fishes recovered from stomachs of oceanic skipjack and the relation of these to the natural food. It was seen that natural food was less than 10 percent of the stomach contents, the rest being formed by bait fish supplied (Raju 1962).

A preliminary survey on the tuna bait fish resources of the Laccadive area has shown the occurrence of a number of species which may be used as tuna live bait. The possibility of using Spratelloides delicatulus, which occurs in large shoals in the area, as a tuna live-bait fish has been indicated (Jones, 1958a, 1958b, 1960a, 1960b, 1962; Thomas 1962b).

The food of skipjack taken by longlining in East African waters has been reported to be made up of squids, fish and planktonic organisms (Williams, 1962). The literature available on the food of skipjack from various parts of the Pacific is extensive (Kishinouye, 1923; Welsh, 1949; Hotta and Ogawa, 1955; Yuen, 1959; Schaefer, 1960; and Yokota et al., 1961). There is general agreement between these and the observations from Indian waters.

5 THE YELLOWFIN TUNA Neothunnus macropterus (TEMMINCK AND SCHLEGEL)

The food of yellowfin tuna ranging from 280 to 800 mm from Minicoy during the 1960/61 season was composed of the same groups of organisms as that of the skipjack caught with them -- fish (72 percent) and crustaceans (26.3 percent) (Fig. 3). This may be owing to the similarity in the habitats of the two species (Thomas, 1962a).

Yellowfin tuna caught on troll lines in the Gulf of Mannar off Tuticorin during July and August 1961, ranging from 560 to 860 mm had fish as the major natural food element, consisting mainly of balistids, and clupeids in small quantities. The second major item was squids (Loligo sp.). Crustacean remains were seen only in traces. About 10 percent of the stomachs were empty (Silas, 1962).

The food of yellowfin tuna from the Central Pacific has been studied in detail and the extensive literature has been reviewed by Reintjes and King (1953). Comparison of yellowfin food with food of the bigeye tuna Parathunnus sibi from the Central Pacific has since been made (King and Ikehara, 1956). Observations are also available from South African and East African waters (Talbot and Penrith, 1960; Williams, 1962) and from Japanese waters (Yokota et al., 1961). It is seen that fishes form the principal item of the food of the species in all the regions.

6 THE NORTHERN BLUEFIN TUNA Kishinoella tonggol (BLEEKER)

K. tonggol caught by trolling in the Gulf of Mannar off Tuticorin from June to September 1961 were found to have crustaceans as the major element of natural food. Digested remains of fishes were seen in the stomachs occasionally (Silas, 1962).

The only other information available on the food of the species is from western, northern and eastern coasts of Australia (Serventy, 1942; 1956). Specimens caught by trolling usually had empty stomachs or the food remains were in an advanced stage of digestion. Most of the fish which contained freshly-captured food in the stomachs were net-caught fish. A wide variety of food organisms were recorded, but pelagic forms predominated. The food consisted mainly of pilchards Sardinops neopilchardus with insignificant numbers of mackerel, Scomber australasicus in specimens from Port Hacking, New South Wales. In Western Australia no particular food preferences were indicated. In Northern Australia, Harengula, pilchards and anchovy predominated among the food items; leatherjackets, garfish, flying fish, Rastrelliger kanagurta, Mugil compressa, Gerres ovatus and various plectognaths also formed the food of the species. Crustacea, particularly stomatopod larvae and prawns were common and cephalopods were frequent among the stomach contents.

7 THE LITTLE TUNNY Euthynnus affinis affinis (CANTOR)

Juveniles of E. affinis affinis caught by boat seines and shore seines and adults caught by hooks and lines at Vizhingam on the west coast and Tuticorin on the east coast have been examined for the food (Kumaran, 1962). Juveniles ranging from 41 to 150 mm had fishes such as Anchoviella tri, A. commersonii, Megalaspis cordyla, Decapterus russelli, Leiognathus insidiator and L. bindus as the major elements of the food. Squids formed a minor item. Squids formed the major constituent of the food of the adults, followed by fishes (Fig. 4).

E. a. affinis measuring from 15 to 70 cm obtained by shore seines, driftnets and hooks and lines at Vizhingam from July 1960 to October 1961 had as food Leiognathus splendens, Sardinella fimbriata, Anchoviella spp., Dussumieria hasselti, Decapterus russelli, Rastrelliger canagurta and Sepia sp. Among these, young clupeids occurred to a far greater extent than other organisms (Bennet, 1962).

Observations on the food of the species from East African waters show that according to the

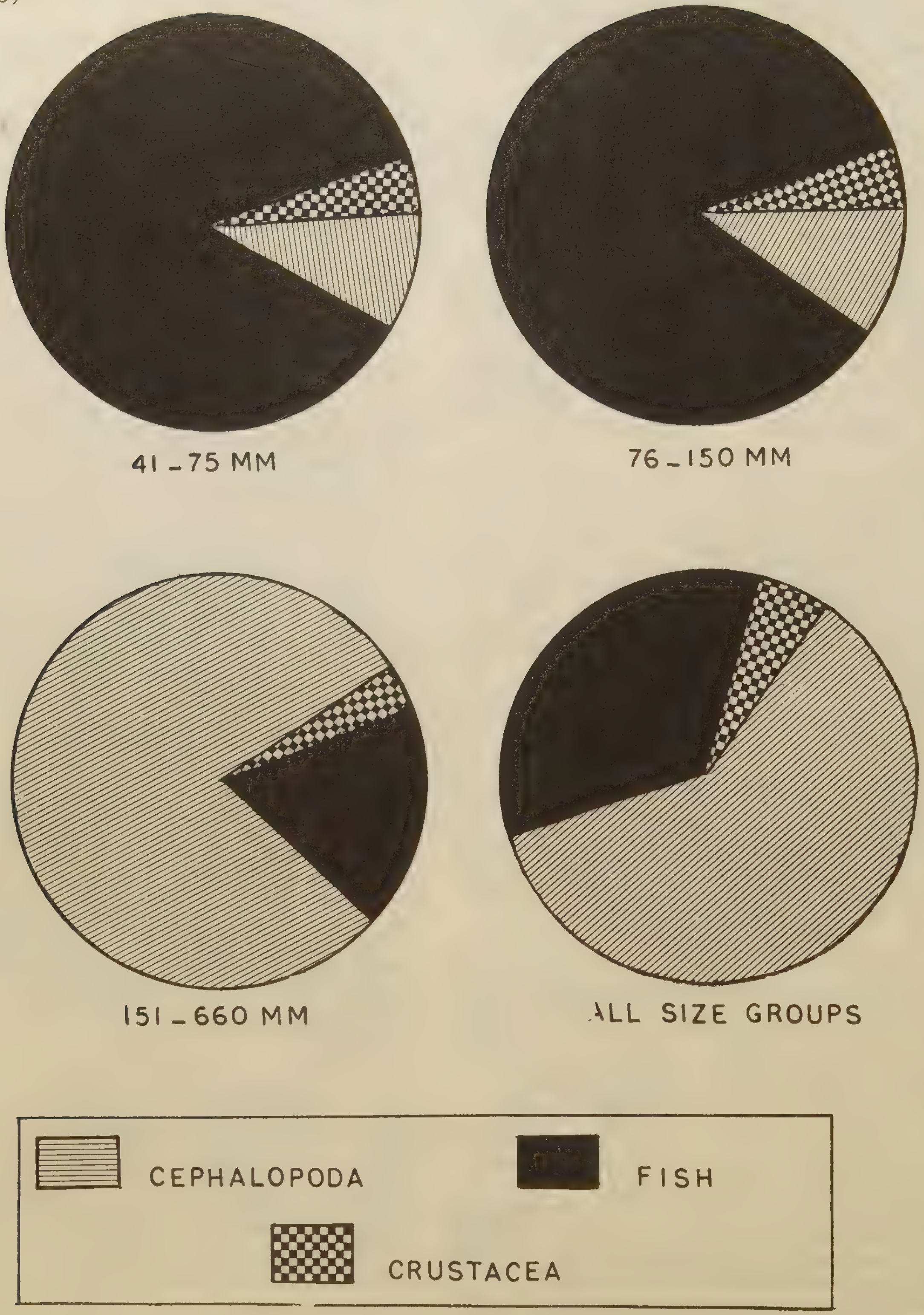


Fig.4. Diagrams illustrating the composition by volume of the stomach contents of *Euthynnus affinis affinis*

frequency of occurrence fishes came foremost, being present in 71 percent of the stomachs containing food. Squids and crustaceans came next, each occurring in 21 percent of the stomachs, followed by zooplankton in 8 percent of the stomachs. The vast majority of the fish remains were of Atherina sp. and clupeids. Twenty-nine percent of the stomachs were empty (Williams, 1962).

Fishes were found to comprise the greatest volume of the food of E. yaito from Oahu, Hawaii; crustaceans next. Occasional gorging on stomatopods and megalopa has also been reported (Tester and Nakamura, 1957). Welsh (1949) observed that crustaceans predominated in the food of E. yaito and fishes came second in importance.

8 THE ORIENTAL BONITO Sarda orientalis (TEMMINCK AND SCHLEGEL)

Studies on the food of adult specimens of S. orientalis caught by hooks and lines and gillnets and of juveniles caught in shore seines and boat seines at centers between Cape Comorin and Trivandrum on the west coast, showed that inshore fishes of medium size formed the major item of the food. Anchoviella tri was the most common fish that occurred in the stomach contents. Squilla larvae formed a minor item (Kumaran, 1962).

S. orientalis caught by pole and line in Japanese waters during the period from February 1959 to October and November 1960 had saury, carangids, Sphyraena sp. and cephalopoda as food (Yokota et al., 1961).

9 GENERAL REMARKS

Only preliminary observations based on the analysis of the stomach contents of limited samples confined to one, or at the most, two areas, and spread over short periods, are available on the food of Indian tunas. The relation between the food organisms found in the stomachs and their availability in Indian waters has not received attention so far.

The examination of the food of A. thazard, A. thynnoides, E. affinis affinis and S. orientalis has shown their reliance on medium-sized inshore fishes such as species of Anchoviella, Sardinella and Leiognathus.

It is interesting to note that actively moving forms -- such as flying fishes and carangids -- and slow moving ones -- such as megalopa and pipe fishes -- are fed upon by the skipjack and yellowfin tuna. The food organisms range in size from small crustacean larvae to large fishes exceeding one-third the size of the fish itself. Inanimate objects such as rubber pieces and plant fibers are also occasionally encountered among the stomach contents. These must have been taken in accidentally.

Detailed studies on the food of tunas will be useful in finding out their preference to certain types of bait fishes. We have no information as to the reason for the lack of response of tunas to bait fish during certain seasons. Attempts are being made to evaluate the tuna bait fish resource of the Laccadive area with a view of expanding the tuna fisheries in this area, where large tuna stocks exist. The available information on the food of Indian tunas, though meagre would tend to show that there is much similarity, in general, with observations from other regions.

It is seen that information is lacking on the food of a few other species of tunas such as Parathunnus obseus mebachi and Gymnosarda unicolor from Indian waters. That more intensive studies have to be undertaken in this field needs hardly any emphasis.

10 SUMMARY

The information available on the food of Indian tunas has been briefly reviewed. The species dealt with are Auxis thazard, Auxis thynnoides, Euthynnus affinis affinis, Sarda orientalis, Kishinoella tonggol, Katsuwonus pelamis and Neothunnus macropterus. The composition of the food of all these species has been given and comparisons drawn with observations from other regions. The need for more intensive work in this field is stressed.

11 ACKNOWLEDGEMENT

Our thanks are due to the Marine Biological Association of India for permission to incorporate in this paper data and figures contained in the papers presented at the Symposium on Scombroid fishes held under the auspices of the Association at Mandapam Camp in January 12-15, 1962.

Experience Paper No. 40

SPAWNING OF THE OCEANIC SKIPJACK
Katsuwonus pelamis (Linnaeus) IN
THE LACCADIVE SEA

By

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Abstract

Preliminary observations on the spawning of *K. pelamis* in the Laccadive Sea have been made and comparisons drawn with observations from different parts of the Pacific. The peak spawning of *K. pelamis* in Laccadive Sea around Minicoy island appears to be mainly February through June. Fractional or multiple spawning is indicated.

Disparity in the sex ratio of *K. pelamis* in Minicoy waters with the males predominating during most months and the occurrence of slightly higher percentages of females among the smaller size groups and males among the larger size groups are indicated. The size of the female skipjack at Minicoy at first maturity is around 400 to 450 mm in total length. The fecundity of 63 skipjack varying in length from 418 to 703 mm observed from Minicoy varied from 151.9 to 1,977.9 thousands of ova in the most mature mode of ovaries.

FRAI DE LA BONITE A VENTRE RAYE *Katsuwonus pelamis* (Linnaeus)
DANS LES EAUX DES LACCADIVES

Résumé

On a effectué des observations préliminaires sur le frai de *K. pelamis* dans les eaux des Laccadives et on les a comparées avec des observations effectuées dans différentes parties du Pacifique. Le frai le plus important de *K. pelamis* dans les eaux des Laccadives aux environs de l'île Minicoy semble intervenir surtout entre février et juin. Ce serait un frai fractionne ou multiple.

On a relevé un déséquilibre dans le rapport des sexes de *K. pelamis* dans les eaux de Minicoy, avec prédominance des mâles la plupart du temps et présence de pourcentages de femelles légèrement plus élevés dans les classes des plus petites dimensions et de mâles dans les classes des plus grandes dimensions. La taille d'une bonite à ventre raye femelle à Minicoy dans sa première maturité est de l'ordre de 400 à 450 mm en longueur totale. La fécondité de 63 bonites dont la longueur allait de 418 à 703 mm et observées à Minicoy variait de 151.900 à 1.977.900 oeufs dans les ovaires de l'état le plus mature.

EP/40

DESOVE DEL BARRILETE *Katsuwonus pelamis* (Linnaeus)

EN AGUAS DE LAS LAQUEDIVAS

Extracto

Se han efectuado observaciones preliminares del desove de *K. pelamis* en aguas de las Laquedivas y se han comparado con otras de diversas partes del Pacífico. La máxima actividad de desove en las proximidades de la Isla Minicoy parece ser de febrero a junio principalmente. Se indica un desove fraccionado o múltiple.

Se señala una disparidad en la proporción de los sexos de *K. pelamis* en aguas de Minicoy, con predominio de los machos durante casi todos los meses y porcentajes ligeramente mayores de hembras en los grupos de menor talla y de machos en los de mayor talla. La hembra del barrilete en Minicoy, al alcanzar la madurez, tiene una talla total de 400 a 450 mm. La fecundidad de 63 barriletes cuya talla variaba de 418 a 703 mm. observados en Minicoy oscilaba entre 151,9 y 1.977,9 miles de huevos en los ovarios más maduros.

1 INTRODUCTION

The oceanic skipjack, Katsuwonus pelamis (Linn.) is the largest single component of world tuna production. In recent years, skipjack have accounted for as much as 35 percent of total tuna production (Chapman, 1962). A major share is harvested from the Pacific. Skipjack remain practically an untapped resource in Indian waters, though there is no reason to suspect they are not abundant. Spawning in space and time is one aspect of skipjack biology on which factual information has been continually added in recent years. This paper is a review of information on spawning of skipjack from the Laccadive Sea. Spawning has been studied in greater detail for Pacific Ocean skipjack.

Schaefer and Marr (1948) were the first to indicate skipjack spawning from January through March in the eastern Pacific and off Costa Rica and upper Panama. They based their work on collection of adults with advanced gonads and juveniles. Schaefer and Orange (1956), from the study of specimens with advanced gonads, and Schaefer (1957, 1959 and 1960), from collection of early skipjack juveniles obtained evidence of spawning around the offshore islands Revilla Gigedo, between Cocos and Clipperton Islands, and indications of probable spawning around Galapagos Islands. The spawning period was June through November.

Many have demonstrated a definite but prolonged spawning from March through September, around the Hawaiian Islands (Eckles, 1949; Brock, 1954; Tester and Nakamura, 1957; Brock and Marr,1960). According to Brock and Marr (1960), there is a seasonal variation in the spawning of Marquesan skipjack, with the principal period from November through April. Matsumoto (1958) on analysing larvae from the central Pacific, concluded that spawning occurred at all longitudes between 120°W and 180° and up to 25°N and as far as the Samoan Islands (14°30'S) in the south, with a definite peak between 4°N and 5°S from May through September.

Kishinouye (1923, 1924 and 1926) found that in Japanese waters, spawning occurred around Ryukyu Islands from May to August. Further extension of spawning areas north of Ryukyu Islands is evident from recent studies of Yokota et al., (1961). The recovery of numerous juvenile skipjack from the stomach contents of yellowfin tuna indicated that the spawning area extends from the equatorial seas to near Tokara from November to May, and also around the southern sea of Kyushu (Yao, 1955). Advanced skipjack gonads were collected from Shikoku between Iyo and Tosa (Hatai et al., 1941) and juveniles in the south sea areas (Yabe, 1953 and 1955). Year-round spawning near the Philippine Islands has been demonstrated by Wade (1950a and 1950b) and Buñag (1956). The following western Pacific areas have been indicated as probable spawning localities, principally from April through July: in Moluccas and Celebes Seas (Shapiro, 1948); around Palau (Hatai et al., 1941, Matsui, 1942); around the equator between 141° and 157°E (Inanmi, 1942, Shimada, 1951a); around northern Marshall Islands (Marr, 1948) and near Phoenix Islands (Shimada, 1951b).

2 SPAWNING OF SKIPJACK IN THE LACCADIVE SEA

Available information from Indian waters is from the Laccadive Sea. Two juvenile skipjack from the Arabian Sea about 350 miles west of the Laccadives were collected by the Dana Oceanographical Expedition (Ehrenbaum, 1924). The Danish Dana round-the-world expedition of 1928-30 obtained a large number of tuna larvae from the Indian Ocean. Examination of the specimens between stations 3905 and 3975 has revealed the presence of larval K. pelamis (Jones, 1959). From 38 larval specimens ranging in length from 2.63 to 7.08 mm and one juvenile measuring 27 mm collected mostly from around the Laccadive Islands and Minicoy (Jones, 1959), spawning was indicated in these regions. From the conditions of gonads of skipjack caught in Minicoy, Jones (1959) indicated the probability of an extended breeding period with January to March as peak breeding time.

2.1 Spawning season

The author has studied spawning around Minicoy Island on the basis of gonads collected from May 1958 to April 1959. A brief account is given below. Details of treatment of materials and data processing are described elsewhere (Raju, 1962a). The percentage of occurrence of fish with mature ovaries during different months; the monthly mean of the 95th centile of the total frequency distribution of the ova in the random samples of the ovaries; and the monthly mean of the "gonad indices" of the skipjack collected at random from the pole and line fishery, were utilized to delineate the spawning periods at Minicoy.

In the previous study (Raju, 1962a) three stages of ovary development (immature, maturing and mature) were based on the mode of the most mature group of ova. But in the present study, use is made of the position of the 95th centile of the total frequency distribution to characterize the size of the most advanced group of ova as selected by Schaefer and Orange (1956). The classification based on the above two methods was very nearly the same. The ovaries containing the 95th centile of the total ova frequency distribution up to 0.15 mm corresponds to immature stage; those between 0.16 and 0.5 mm to maturing stage; those between 0.51 to 0.72 mm to mature stage. The ovaries designated as mature represent the highest degree of sexual maturity of the ovaries collected from Minicoy in 1958 and 1959.

Though regular weekly collections of gonads from the random samples of skipjack landing were obtained, only alternate weekly samples were utilized for ova diameter studies, as this required a great deal of time. Fig. 1 plots the percentage of occurrence of skipjack in different maturity stages. It is seen that the occurrence of mature ovaries was first observed in November and they continued more or less in the same proportion from November through January. Relatively large percentages of these ovaries were encountered in the samples from February through June.

They occurred in the samples up to July though percentages were much reduced. The mature gonads from February through July show practically no trend in the development of the ova, but merely fluctuate in that range. Ovaries with egg remnants were observed from February, though no ripe ovary in the running condition was encountered. What was believed to be a spent ovary was obtained in April. But spent ovaries with the typical bloodshot and flabby appearance were observed in fairly good numbers during June and they were frequent during July and August. From September there was a sudden decline in the proportion of occurrence, perhaps showing that recoveries of the ovaries had started without much delay in preparing for the next spawning season. Fig. 2 gives the monthly frequency distribution of the ovaries with different 95th centile groups of ova. The monthly means of these are also shown by the thick connecting line.

The "gonad index" -- the function of fish length and gonad weight (Schaefer and Orange, 1956) to determine rapidly, but objectively, the state of maturity of gonads, was determined for each fish in the weekly random samples. The monthly frequency distribution of the skipjack with various gonad indices, with their mean for each month, is given in Fig. 3. Fig. 4 plots gonad indices and the positions of the 95th centile of the ova diameter frequency for each specimen and for three arbitrary stages of maturity.

Something more is to be added about the period August to October 1958, during which the mature gonads were absent from the samples. This is the monsoon period when the fishery becomes very poor. Fishing becomes occasional and is restricted to the eastern side of the island. There is no information on whether mature females were absent on the regular island fishing grounds or only absent in the particular area where fishing was restricted. But when fishing resumed in mid-October, mature females were not encountered and from November through January they were apparently in reduced proportions. This leads one to ask whether there is a definite spawning period or at least a peak spawning season, from February through June.

Mature ovaries first appear in November. But as they are not fully ripe, some time must elapse before they begin to spawn. Unfortunately no information is available on the rate of ova development. Jones (1959) collected three larvae during early December. The possibility that those gonads which mature during November can reach spawning condition and commence first spawning in December around this island is not ruled out. Dr. Jones made no collection of larvae during months other than December to March in 1958-59 around Minicoy.

2.2 Size of mature ova

Ova diameters of K. pelamis, observed from the advanced ovaries by many workers in different parts of the Indo-Pacific, range mostly from 0.55 to 0.80 mm. This is believed to represent a somewhat earlier stage of maturity. The largest transparent ova with a single golden yellow oil globule recorded from a hermophrodite skipjack from Minicoy was 0.809 mm in diameter (Raju, 1960). The largest ova that Brock (1954) found measured 1.125 mm in diameter and this perhaps is close to the size of the fully ripe ova in normal individuals.

2.3 Indication of spawning

The spawning places of tunas are indicated from the evidence based on the

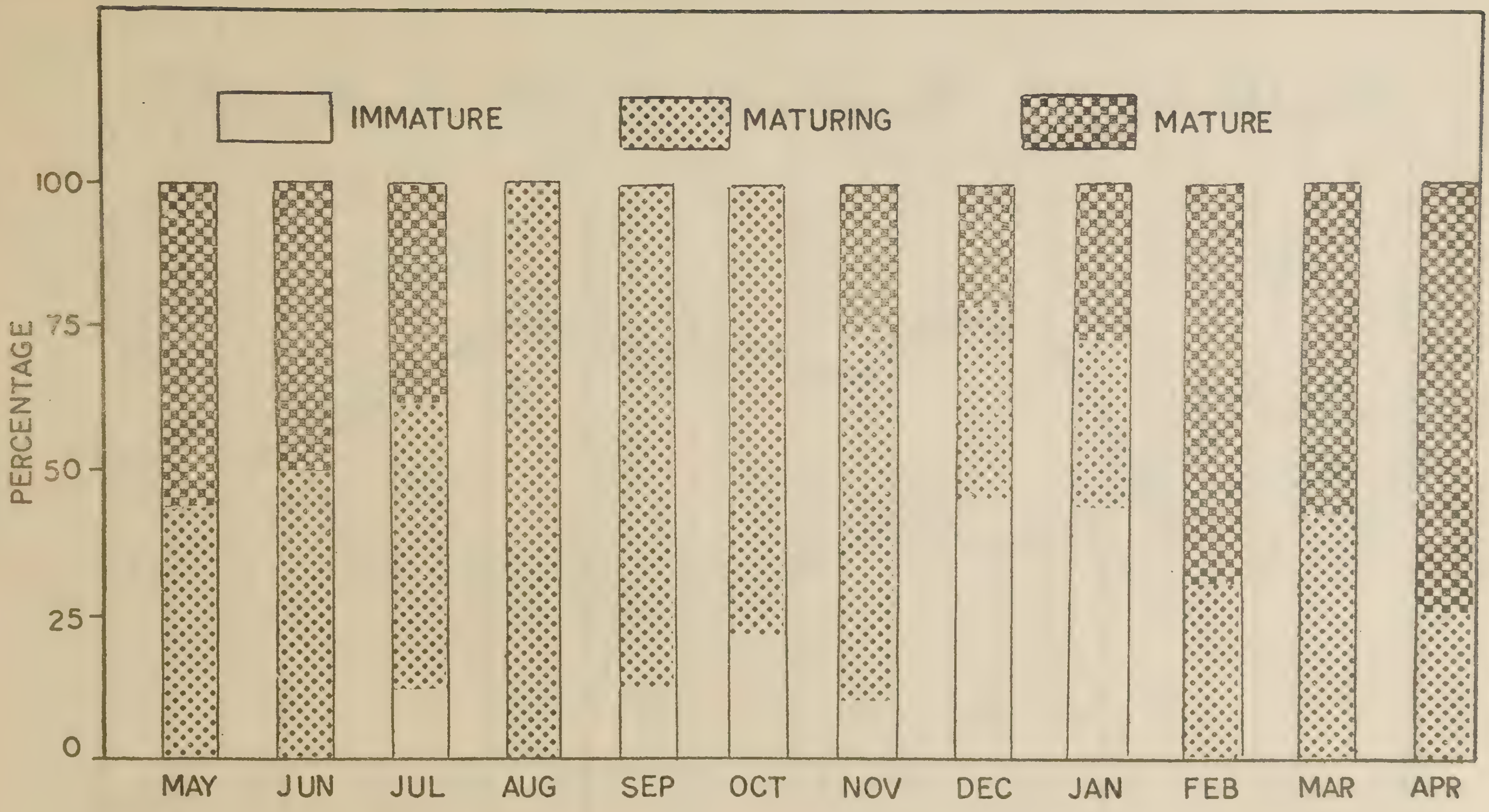

Fig. 1. Monthly percentage frequency of occurrence of the skipjack with different maturity stages among the random samples obtained from the pole and line fishery at Minicoy, 1958 to April 1959

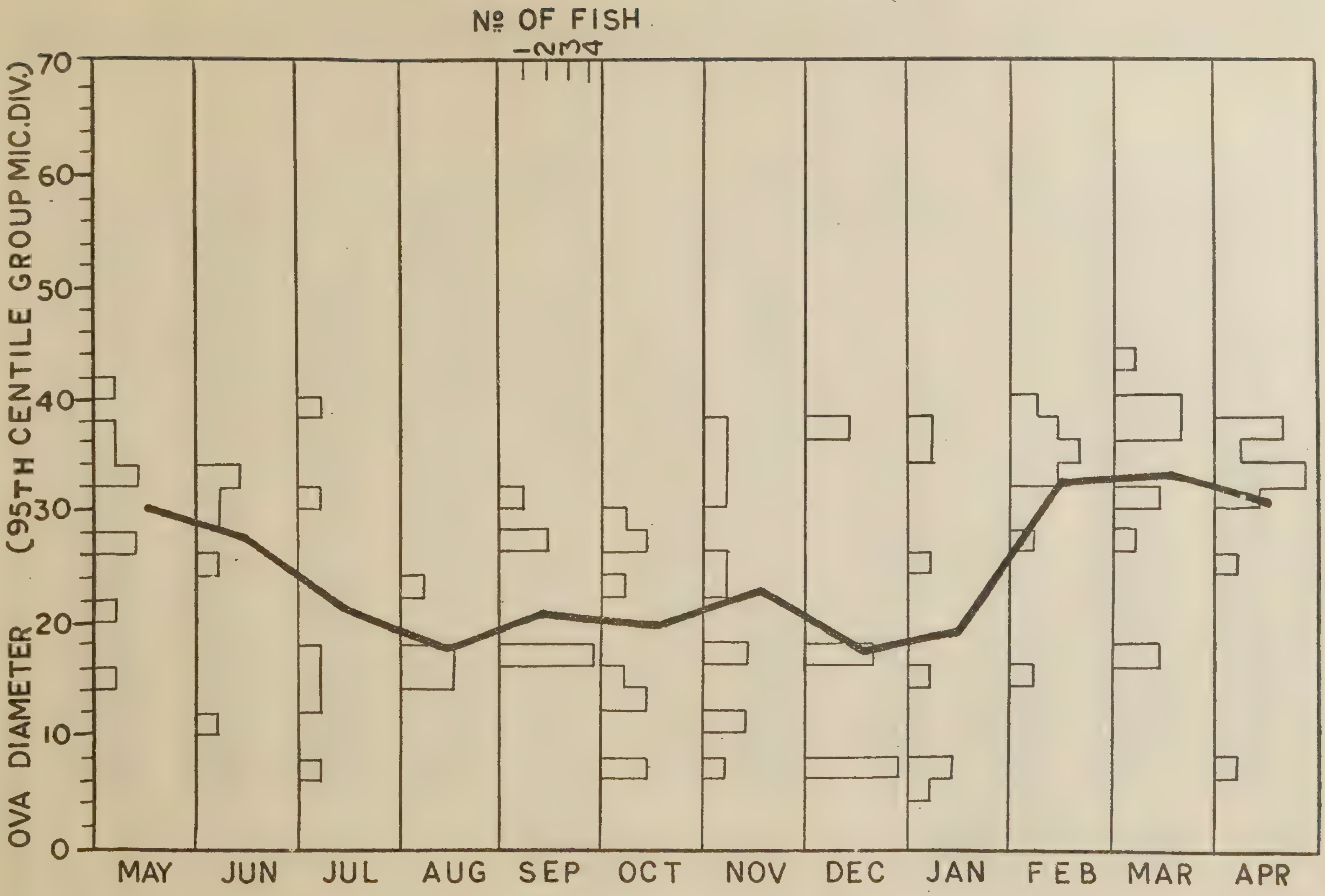

Fig. 2. Monthly frequency distribution of ovaries with 95th centile groups of ova obtained from the random samples of pole and line fishery, May 1958 to April 1959, at Minicoy (The monthly means are connected by thick lines. One micrometer division equals 0.0165 mm)

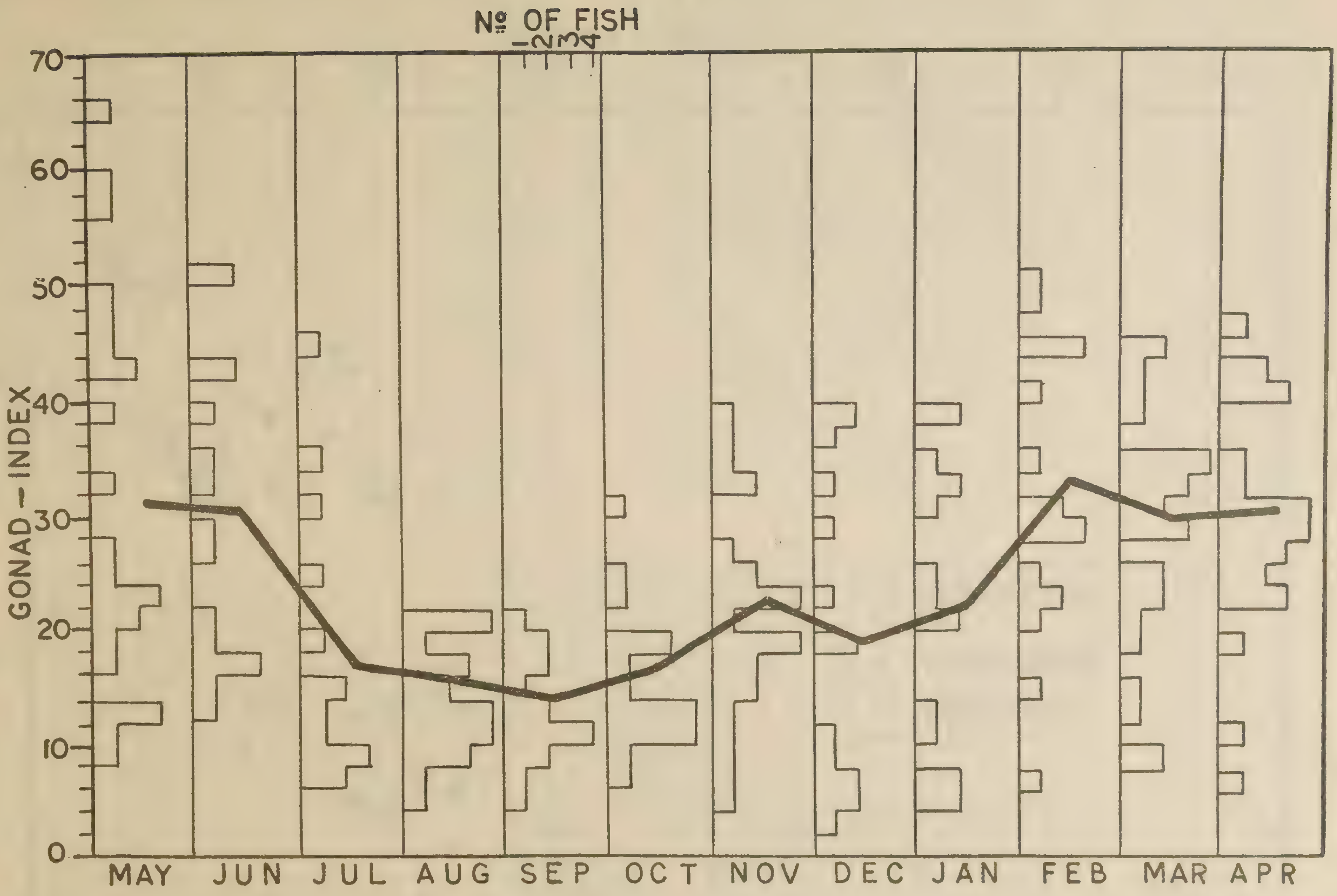

Fig. 3. The monthly frequency distribution of the female skipjack with different gonad indices observed from the random samples obtained from the pole and line fishery at Minicoy, May 1958 to April 1959 (The monthly means are connected by the thick line)

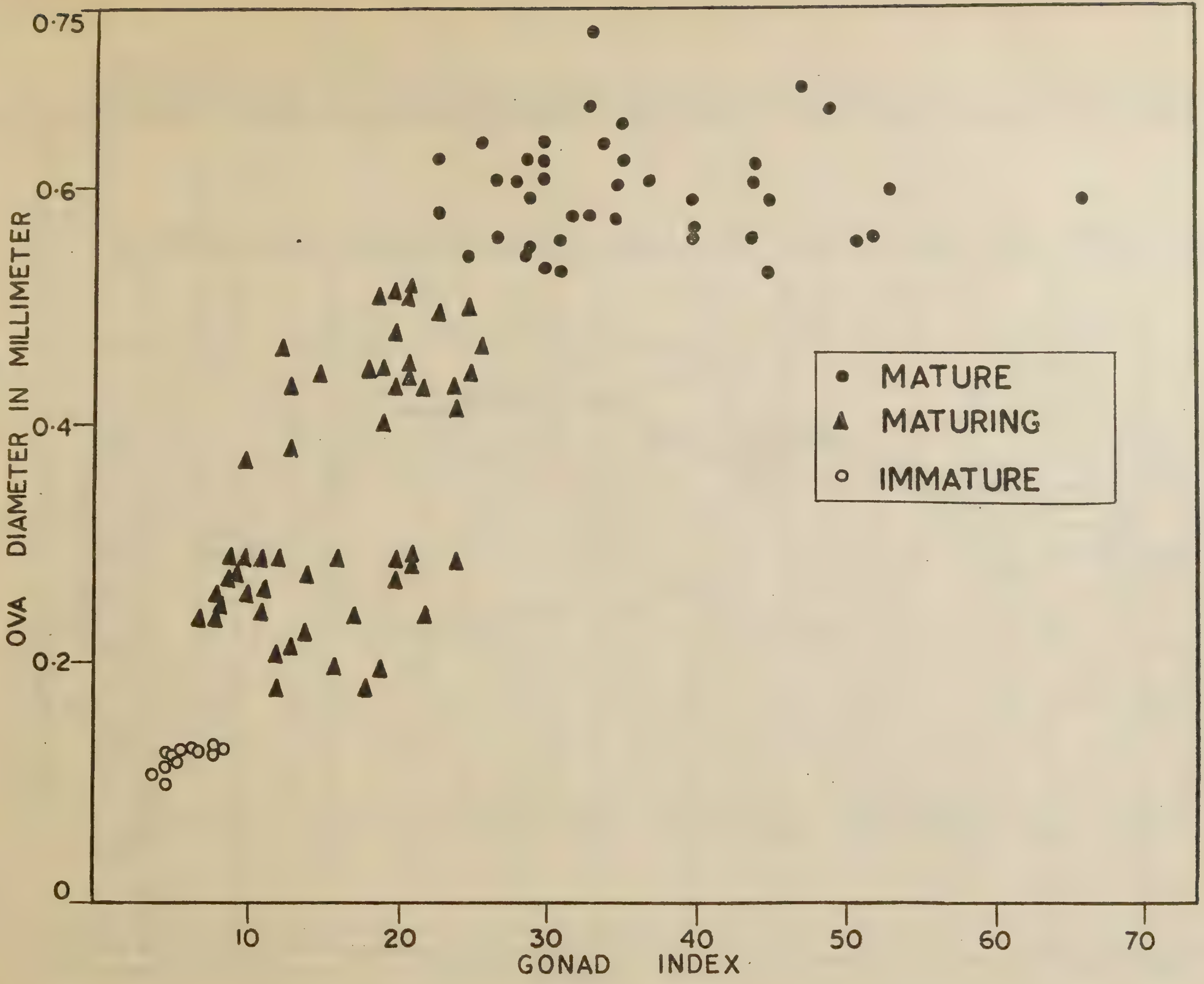

Fig. 4. Scatter diagram showing the relation between the gonad index and the position of the 95th centile of the ova diameter frequency of 103 skipjack observed from the random samples obtained from the pole and line fishery at Minicoy, May 1958to April 1959

examination of advanced gonads, collection of larvae and juveniles in plankton hauls or recovery of them from the stomach contents of pelagic fishes. Inferences on spawning around Minicoy and the probable season are made on the assumption that the occurrence of the ovaries in advanced stages of sexual maturity, or recently spent, are indicative of spawning near the place and time of capture.

The presence of egg remnants in certain of the ovaries collected from Minicoy is also a proof of spawning having taken place there. But the application of the above evidence to the spawning of skipjack (and other tunas as well) has always the limitation that skipjack is a pelagic fish capable of migrating great distances in a few days. On the other hand, the presence of young larval stages around Minicoy (Jones, 1959) provides direct evidence of recent spawning in the vicinity of the island, provided the transport of larvae by current is not considerable. Ther is no information on the direction and the velocity of the currents around Minicoy, the duration of the incubation period of skipjack eggs, the size of the larvae at hatching and the migration of adult skipjack.

2.4 Frequency of spawning

A study of the size distribution of ova in mature skipjack ovaries from Minicoy waters reveal two prominent batches of developing ova in addition to the stock of ova. The growths of the two batches could be traced from the maturing up to the mature stages of the ovaries described. These have been described in detail elsewhere (Raju, 1962a). But the absolute time interval of the growth of the batches of ova is unknown. In the fully-spent gonads, the two modes or batches of mature ova completely disappear, leaving a single mode of immature stock of ova. It was also found that in the ovaries in which the egg remnants occurred there were again two modes, except in three ovaries taken in April and July in which there was only a single mode. This clearly indicates that ova are spawned in batches, but how many times the ova are released is not known. Buñag (1956) is of the opinion that several batches of eggs are released before it becomes completely spent. Brock (1954) bases the possibility of skipjack from Hawaii spawning several times, on three lines of evidence, viz., the multi-modal distribution of ova diameters during spawning season and its absence at other times; the absence of an overall trend in ova diameter during spawning season and the absence of fish that are obviously spawned out until after the end of the spawning season. Thus, though fractional spawning has been indicated for skipjack and various other species of tuna, the exact number of batches released is still a riddle to fishery biologists.

3 GENERAL OBSERVATIONS

During observations from Minicoy Island, a very high percentage of males was found, particularly during the supposed active spawning period. This agrees with Brock (1954), Tester and Nakamura (1957) and Wade (1950a). Schaefer and Orange (1956) found a greater proportion of females during most of the periods in which they examined eastern Pacific skipjack. During the monsoon period, the percentage of females was greater. Table I shows the numbers of the males and females encountered in the random samples, and their percentages for each month. In Tables II and III are tabulated the percentage frequency of the two sexes among various groups during different months of observations, and Fig. 5 depicts the percentages of fish of the two sexes in all samples taken together within each size group. It appears there is a slightly greater percentage of females among smaller size categories and among larger size categories, a greater percentage of males. The relative percentages of the two sexes are cleary seen in Table IV where they are grouped into four broad size groups.

The smallest two skipjack that had mature ovaries were 390 mm and 396 mm in standard length. The largest with immature gonad was 481 mm. But ordinarily, fish over 450 mm with immature gonads were very rare at Minicoy. Spent ovaries were encountered in the size group 400 to 450 mm. Therefore this appears to be the size of first maturity. This agrees with the observations of Brock (1954), Wade (1950a) and Marr (1948). But Schaefer and Orange (1956) found that in the eastern tropical Pacific, the size at first maturity is near 550 mm and that a large share of individuals do not mature below 600 mm in certain areas. According to Brock (1954), skipjack reach 400 to 450 mm in one year. He concluded they first mature when about one year old.

There is not much information on fecundity. The available fecundity estimates are made from the total number of ova in the most mature mode of the ovaries in which there was no indication of

Table I

Monthly sex ratios of skipjack observed from the random samples of pole and line fishery at Minicoy Island during the period May 1958 to April 1959

No.	Months	Total number of specimens examined	Number of Males	Number of Females	Percentage of Males	Percentage of Females
1	May	274	234	40	85.4	14.6
2	June	102	79	23	77.5	22.5
3	July	55	20	35	36.4	63.6
4	Aug.	118	40	78	33.8	66.2
5	Sept.	132	58	74	43.1	56.9
6	Oct.	175	101	74	57.8	42.2
7	Nov.	233	99	134	42.5	57.5
8	Dec.	261	173	88	66.3	33.7
9	Jan.	254	189	65	74.4	25.6
10	Feb.	245	197	48	80.5	19.5
11	Mar.	167	109	58	63.5	34.7
12	Apr.	213	156	57	73.2	26.8
	TOTAL	2,229	1,455	774	65.3	34.7

Table II

Percentage frequency of female skipjack of different size groups observed from the random samples obtained from the pole and line fishery at Minicoy Island during different months of the period May 1958 to April 1959

	Total length in millimeters															
Months	381 to 400	401 to 420	421 to 440	441 to 460	461 to 480	481 to 500	501 to 520	521 to 540	541 to 560	561 to 580	581 to 600	601 to 620	621 to 640	641 to 660	661 to 680	681 to 700
May	..	4.1	4.1	8.3	12.5	20.9	12.5	29.3	8.3	..	..	..	..	..	..	..
June	..	..	6.2	18.8	31.3	18.8	6.2	12.5	6.2	..	..	..	..	..	..	..
July	..	..	7.7	15.4	30.7	23.1	23.1	..	..	..	..	..	..	..	..	..
Aug.	5.3	..	5.3	10.5	36.8	21.0	10.5	..	..	..	..	5.3	..	..	..	5.3
Sept.	..	..	6.7	13.3	13.3	26.7	13.3	6.7	13.3	..	..	6.7	..	..	..	..
Oct.	..	5.6	5.6	27.7	22.1	11.1	5.6	5.6	11.1	..	..	..	..	5.6	..	..
Nov.	..	8.0	8.0	8.0	24.0	8.0	8.0	16.0	8.1	4.0	4.0	..	..	4.0	..	..
Dec.	6.7	20.0	33.2	6.7	13.3	6.7	6.7	6.7	..	..	..	..	..	..	..	..
Jan.	5.9	23.5	17.6	5.9	5.9	11.8	17.6	5.9	..	5.9	..	..	..	..	..	..
Feb.	..	5.6	11.1	16.6	11.1	16.6	5.6	16.6	5.6	..	..	..	..	..	..	..
Mar.	..	..	3.7	3.7	11.1	22.3	3.7	3.7	3.7	3.7	14.8	14.8	7.4	3.7	..	..
Apr.	..	4.0	4.0	4.0	8.0	8.0	4.0	8.0	8.0	8.0	8.0	12.0	12.0	8.0	..	4.0

Table III

Percentage frequency of male skipjack of different size groups observed from the random samples obtained from the pole and the line fishery at Minicoy Island during different months of the period May 1958 to April 1959

	Total length in millimeters															
Months	381 to 400	401 to 420	421 to 440	441 to 460	461 to 480	481 to 500	501 to 520	521 to 540	541 to 560	561 to 580	581 to 600	601 to 620	621 to 640	641 to 661	661 to 680	681 to 700
May	3.4	1.7	11.9	8.4	11.9	13.6	8.4	13.6	10.2	8.4	5.1	1.7	1.7	..	..	..
June	..	..	..	..	37.9	21.6	13.5	10.8	5.4	5.4	2.7	2.7	..	..	..	..
July	..	..	..	..	55.6	11.1	..	11.1	11.1	..	11.1	..	..	..	..	..
Aug.	..	..	..	..	45.4	36.4	..	9.1	9.1	..	..	..	..	..	..	..
Sept.	..	5.3	..	..	10.5	15.8	21.0	10.5	..	10.5	10.5	5.3	5.3	5.3	..	..
Oct.	..	..	..	8.4	4.0	28.0	20.0	12.0	4.0	4.0	4.0	8.0	8.0	..	..	..
Nov.	..	..	..	..	6.4	22.5	16.1	19.4	13.0	9.7	6.4	3.2	3.2	..	..	..
Dec.	..	...	3.2	3.2	38.7	29.1	13.0	3.2	3.2	3.2	3.2	..	..	..	..	..
Jan.	..	..	2.1	14.5	18.7	20.8	12.5	6.2	6.3	..	4.2	6.3	4.2	2.1	2.1	..
Feb.	..	..	13.9	19.4	11.1	8.3	5.6	5.6	2.8	13.9	8.3	8.3	2.8	..	..	..
Mar.	..	..	5.6	11.1	16.6	11.1	16.6	..	5.6	5.6	11.1	11.1	..	..	5.6	..
Apr.	..	..	..	..	..	7.7	11.5	15.5	3.8	3.8	7.8	15.5	19.1	11.5	3.8	..

Table IV

Percentage frequency of the two sexes of skipjack observed among the random samples obtained from the pole and line fishery at Minicoy Island during the period May 1958 to April 1959

	Total length in millimeters			
Sex	381 to 460	461 to 540	541 to 560	621 to 700
Female	27.7	54.5	13.1	4.7
Male	12.5	58.6	22.6	6.2

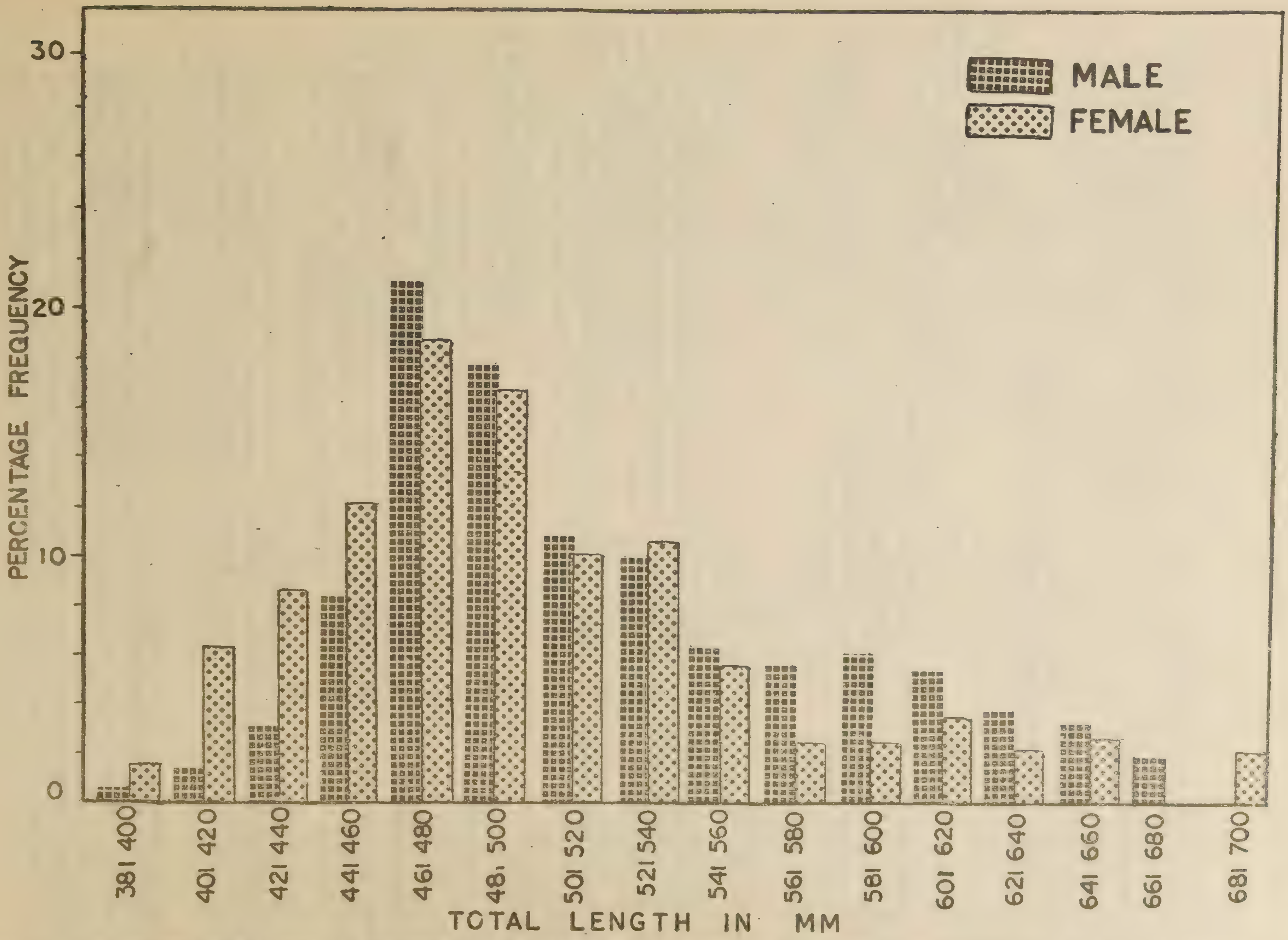

Fig. 5. The percentage of length frequency of the skipjack of the two sexes at Minicoy observed among the random samples obtained from tho pole and line fishery during the period May 1958—April 1959

previous spawning in the immediate past. Schaefer(1961) found, from fourteen sets of ovaries collected near the mouth of the Gulf of California, 407 to 1327 thousands of ova in the most advanced mode from skipjack ranging in total length from 659 to 699 mm. Raju (1962b) observed that in 63 Minicoy skipjack ranging from 418 to 703 mm ova numbered from 151.9 to 1,977.9 thousands in the most advanced mode with a wide range of variations among individuals of the same size group.

4 DISCUSSION

Regarding the Pacific spawning season, we find a variety of opinions. In the final analysis it appears mainly to oscillate between two opinions: (i) that they spawn year round with perhaps some peak periods and (ii) that there is a definite spawning season. Many appear to favor the former. One handicap in the study of spawning of skipjack from the Laccadive Sea has been the lack of specimens in ripe running condition and the gonads indicating almost the same level of maturity. It may not be that the gonads remain in a single developmental stage, but it may be that schools of fish that have gonads at more or less the same stage of maturity are continually coming to the waters and become available to the fishery. The lack of ripe specimens in the catches may be due to the fish moving offshore or to deeper waters to spawn or it may be due to the schools breaking up and ceasing to feed (Schaefer and Orange, 1956). A thorough study of the differences in the individual gonads within the schools, or variations between schools, is necessary to ascertain the annual changes in the degree of ripeness of gonads.

The waters around many oceanic islands are known to be definite spawning grounds of this species.

The preponderance of males during the spawning season has also been reported by a number of workers in the Pacific. The cessation of female feeding activity during spawning or their migrations have been offered as explanations.

Within this widely-distributed species we find wide variations in spawning season, spawning intensities, size at first maturity and fecundity in different areas. Whether these variations are results of race-connected characteristics of the different "races" or "stocks" occupying different regions, is an important problem awaiting solution.

5 SUMMARY

1. Preliminary observations on the spawning of K. pelamis in the Laccadive Sea have been made and comparisons drawn with observations from different parts of the Pacific.

2. The peak spawning of K. pelamis in the Laccadive Sea around Minicoy Island appears to be mainly February through June.

3. Fractional or multiple spawning is indicated.

4. Disparity in the sex ratio of K. pelamis in Minicoy waters with the males predominating during most months and the occurrence of slightly higher percentages of females among the smaller size groups and males among the larger size groups are indicated.

5. The size of the female skipjack at Minicoy at first maturity is around 400 to 450 mm in total length.

6. The fecundity of 63 skipjack varying in length from 418 to 703 mm observed from Minicoy varied from 151.9 to 1,977.9 thousands of ova in the most mature mode of ovaries.

6 ACKNOWLEDGEMENT

The author wishes to express his gratitude to Dr. S. Jones, Director, Central Marine Fisheries Research Institute, Mandapam Camp, for guidance and encouragement during the present investigation and for critically reading the manuscript and suggesting improvements. The author's thanks are also due to Mr. M. S. Rajagopalan for the help rendered in the preparation of this paper.

Experience Paper No. 41

A CONTRIBUTION TO THE BIOLOGY OF PHILIPPINE TUNAS

By

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Abstract

The Philippine Bureau of Fisheries M/V Malasugui a 110-ton long-liner from Japan, made three tuna longline exploratory cruises in 1960 in the southern part of the Philippines. In these cruises, deep-swimming yellowfins predominated the catch.

Many yellowfins show little variation in size range whereas the bigeyes had a wide range in length and weight possibly indicating that they belong to several year classes.

The length-weight relationship of the tuna species were determined by sexes, by using the method of least squares. There was very little difference in the regression coefficient between the males and females.

The feeding habits were determined by examination of their stomach contents. It was found out that both yellowfin and bigeye tuna have more or less the same food habit. One-third of the food consists of fish, one-third consists of molluscs especially squids, and one-third consists of crustacean decapods.

The first gill arch on the right side of yellowfin and bigeye specimens were removed and the number of gill rakers counted. The numbers of gill rakers in the upper arch of both fish were almost identical in both species; however, the mean value in the lower arch is 20.27 for yellowfin and 18.61 for the bigeye.

The troll catch of the research vessels S. F. Baird, T.N. Gill and D.S. Jordan of the Philippine Fishing Program of the U.S. Fish and Wildlife Service in 1947 - through 1949 were treated statistically to determine the length-weight relationships of the five most common species of tuna caught by trolling. There were no significant differences between the male and female growth rates. In the dogtooth and scaly tuna which were less common, the length-weight relationships were determined with the sexes combined.

The gonad index for the five female species of tuna were determined using the method described by Kikawa (MS). It was seen that the skipjack and yaito tuna breed during the greater part of the year in Philippine waters.

Few female yellowfin had gonad index of more than 3 and this is understandable for the older and therefore breeding fish are caught only by longline in these areas and are therefore unavailable to the troll fishery. Nevertheless, there are breeding fish found in the catch.

It was noted that because the gonad index may decrease even in larger fishes, there appears a resorption of the eggs in between the breeding period of the fish during the non-breeding season.

CONTRIBUTION A LA BIOLOGIE DU THON DES PHILIPPINES

Résumé

Le M.V. Malasugui, palangrier japonais de 110 tonneaux du Bureau philippin des pêches, a effectué en 1960 au sud des Philippines trois campagnes de recherches sur le thon. Le gros des prises, aux palangres, a consisté en thons à nageoires jaunes se déplaçant en eau profonde.

Si l'examen de nombreaux thons à nageoires jaunes n'a pas révélé d'importantes variations de taille, les thons obèses offraient une gamme étendue de longueurs et de poids, dénotant peut être la présence de plusieurs classes d'âge.

Le rapport longueur/poids des diverses espèces de thon a été calculé, par sexe, en utilisant la méthode des moindres carrés. Le coefficient de régression variait très peu entre mâles et femelles.

Les habitudes alimentaires ont été déterminées par l'examen des contenus stomacaux. On a constaté que les thons à nageoires jaunes et les thons obèses avaient à peu de chose près les mêmes habitudes alimentaires. Leur nourriture consiste pour un tiers de poissons, un tiers de mollusques (surtout des calmars), et un tiers de crustacés décapodes.

Sur les spécimens de thons à nageoires jaunes et de thons obèses, on a retiré le premier arc branchial de droite et compté le nombre de branchiospines. Dans l'arc branchial supérieur des deux espèces, le nombre de branchiospines est à peu près identique; pour ce qui est de l'arc inférieur toutefois, la valeur moyenne est de 20, 27 pour le thon à nageoires jaunes et de 18, 61 pour le thon obèse.

Les prises effectuées aux lignes trainantes de 1947 à 1949 par les navires de recherche S.F. Baird, T.N. Gill et D.S. Jordan, relevant du Programme de pêche dans les eaux philippines du Fish and Wildlife Services des Etats-Unis d'Amérique, ont fait l'objet d'un traitement statistique visant à établir le rapport longuer/poids des cinq espèces de thon les plus fréquemment capturées à la traine. On n'a pas constaté de différences importantes entre les taux de croissance des mâles et des femalles. Pour le thon "dogtooth" (Gymnosarda nuda) et le "scaly tuna", plus rares, on n'a pas distingué entre les sexes pour le calcul du rapport longueur/poids.

Pour les femelles des 5 espèces de thon, l'indice de maturité des gonades a été determiné par la méthode décrite par Kikawa. On a constaté que la bonite à ventre rayé et le thon "yaito" (Euthynnus affinis) se reproduisent durant la plus grande partie de l'année dans les eaux philippines.

Peu de spécimens femelles de thons à nageoires jaunes avaient un indice de plus de 3, ce qui est compréhensible car dans ces régions les thons en âge de se reproduire ne sont capturés qu'aux palangres, et ne figurent généralement pas parmi les prises de la pêche à la traine. On a cependant pêché quelques poissons en période de reproduction.

On a noté que, l'indice de maturité des gonades pouvant décroître même chez les grands poissons, les oeufs se résorbent entre les périodes de ponte en dehors de l'époque du frai.

CONTRIBUCION A LA BIOLOGIA DE LOS ATUNES DE FILIPINAS

Extracto

El barco a motor Malasugui de la Oficina de Pesca de Filipinas, que es un palangrero del Japón de 110 toneladas, realizó en 1960 tres cruceros exploratorios para la pesca del atún con palangre en la parte meridional de las Filipinas. En tales cruceros predominaban en las capturas los atunes de aleta amarill que nadaban a profundidad.

Muchos de los atunes de aleta amarilla registran poca variación en la talla, en tanto que los atunes patudos varían mucho de talla y de peso, lo que indica que posiblemente pertenecian a varias clases anuales.

Las relaciones talla-peso de las especies de atún fueron determinadas por sexos, utilizando el método de los mínimos cuadrados. Se observaron diferencias muy pequeñas en el coeficiente de regresión entre los machos y las hembras.

Se determinaron los hábitos alimentarios mediante el examen del contenido estomacal. Se observó que, tanto los atunes de aleta amarilla como el patudo, tienen poco más o menos los mismos hábitos de alimentación. Una tercera parte del alimento estaba constituido por peces, otra tercera parte por moluscos, especialmente jibias y el resto por crustáceos decápodos.

Se retiró el primer arco branquial del lado derecho de ejamplares de atún de aleta amarilla y de patudo y se contó el número de branquispinas. El número de éstas en el arco superior era casi idéntico en ambas especies; sin embargo, el valor medio en el arco inferior es de 20, 27 para el atún de aleta amarilla y de 18, 61 para el patudo.

Las capturas con curricán realizada en 1947 a 1949 por los barcos de investigación S. F. Baird, T.N. Gill y D.S. Jordan del Programa de Pesca en Filipinas del Servicio de Pesca y Vida Silvestre de los E.U.A. fueron tratadas estadísticamente para determinar la relación talla-peso de las cinco especies más corrientes de atún capturadas por tal método. No se registraron diferencias sensibles entre las tasas de crecimiento de machos y hembras. En las dos especies menos abundantes se determinó la relación talla-peso combinando ambos sexos.

El indice de madurez para las hembras de las cinco especies de atún, se determinó siguiendo el método descrito por Kikawa (MS) Se pudo observar que el barrilete y la bacoreta se reproducen durante la mayor parte del año en aguas filipinas.

Pocas hembras de atún de aleta amarilla tenían índice de madurez superior a 3, lo cuál es comprensible si se considera que los ejemplares más viejos, y por lo tanto en reproducción, se capturan solamente con palangre en estas zonas y por consigniente no se logran en la pesca a la carrera. A pesar de ello, en las capturas se encontraron peces en pena madurez.

Se pudo notar que como el indice de madurez puede disminuir aún en los individuos de mayor tamaño se verifica una reabsorción de los óvulos en medio del período de reproducción del pez durante la temporada di inactividad reproductiva.

1 INTRODUCTION

The commanding position of tunas in world fisheries attracts increasing attention to the exploration of tropical Pacific waters lying within this belt of warm waters. The Philippine seas naturally constitute an integral unit of the great tuna fisheries of the Asiatic Quadrant of the Pacific, which in the past has produced 78 percent of the Pacific tonnage. Realizing this potentiality of Philippine waters for tuna exploitation ventures, the Philippine Bureau of Fisheries launched an investigation of the areas that bear promise of excellent yields in the light of our present knowledge of the oceanography of Philippine waters. Such areas as southeastern Mindanao where the Pacific Equatorial Current ends, and northeastern Luzon, which is known to be within the path of tuna migration, will be intensively investigated. For this purpose, the M/V Malasugui of the Philippine Bureau of Fisheries will be used.

Except for the tuna exploration work carried out by the Japanese in scattered areas in the Philippines, there has been no systematic survey undertaken within territorial waters for exploiting the tunas. The Philippine Fishery Program of the United States Fish and Wildlife Service made several attempts using the well-known Japanese longline. Although the results obtained were not altogether encouraging, undoubtedly because of the lack of factual oceanographic data, the exploratory work led to an appreciation of the importance of collecting oceanographic information and correlating it with the tuna catch. This scheme of making hydrographic observations hand in hand with tuna fishing operations has been widely practiced by the Japanese, who have developed the tuna longline technique to a high degree of efficiency.

Although we have very few data on the tuna potentials of Philippine territorial waters, the Japanese, Taiwanese and Okinawan tuna longline fishermen knew of the high-yielding capacity of these waters long before the Philippines recognized the importance of the fishery. In fact, every now and then, longline sampans from Taiwan and Okinawa are encountered either poaching or seeking shelter in Philippine waters. During the third exploratory trip of M/V Malasugui, the activities of Philippine fishermen were cut short when two Taiwanese vessels were apprehended with their lines out, very near Basilan Island. Martin (1938) and Domantay (1940) described Japanese methods of fishing and Warfel (1950) evaluated the tuna potentials of the country.

Tapiador (1951) described the fishing venture of two Taiwanese-made vessels (sampans) which made nine longline fishing trips in nine months in the Sulu Sea, Palawan and western Mindoro. The two vessels M/V Dinia and Nelly, 38.32 and 47.27 gross tons respectively, landed together more than 100 tons of tuna and tuna-like fish. These two vessels used the Japanese method of longline and brought to the Philippines, Taiwanese fishermen to teach the Filipino fishermen this technique of fishing.

At the time, the catch which was mostly of yellowfin, bigeye and swordfish, could not be disposed of through the fresh fish market because of their size, and the venture folded up due to lack of good market value as well as of canneries which could process the excess catch.

2 STUDIES ON TUNAS CAUGHT BY LONGLINE

The Bureau of Fisheries initiated in February 1957 a tuna longline fishing exploration by using Japanese techniques to determine the deep-swimming tuna potentials of Philippine territorial waters. A 30-ton, 135 h.p. vessel, the M/V David Starr Jordan, was fitted for the use of the Japanese longline gear from Japan. Only four fishing cruises were made, however, by this vessel from 1957 to 1958 due to its small size and aged condition, involving a total of 24 settings of 1,835 hooks.

The exploration work for tuna was resumed only early in 1960 upon acquisition of a 110-ton fishing vessel, the M/V Malasugui from Japan as part of the Japanese Reparations to the Philippines. This vessel is of the class of several fishing vessels from Japan and can be used to fish in all parts of Philippine waters.

The tuna longline gear used by the M/V Malasugui was imported from Japan and of Kuralon material, a kind of synthetic fiber. The gear was described by Dinglason (MS). For this study a device was made such that the waters around the Philippines were divided into grids of 400 square miles each.

Each degree of latitude and longitude has been divided into three equal parts of twenty minutes thus forming nine square blocks for every degree of water area which were called "fishing blocks". These were affixed with the subscripts a, b, c, and x, y, z, depending on the latitude and longitude wherein they fell. The Phillippine territorial waters are, therefore, divided into more than 1,000 fishing blocks. It was intended for this exploratory program to cover these areas by three respective settings per month. Since each block should be investigated at least once during the two main monsoon seasons to determine its effect, if any, on the movement of these fish, this task alone necessitates approximately 36,000 settings in the more than 1,000 fishing blocks available for exploration. However, because of the numerous Japanese gear that the M/V Malasugui is made to experiment on, so far only three exploratory longline fishing cruises for tuna with a total of 27 sets involving 10,918 hooks in the southern parts of the Philippines (Sulu Sea and Celebes Sea) were made. A total of 51 sets involving 24,525 hooks have been made by both the Jordan and the Malasugui since 1957.

Experiments were conducted on the presence, absence and position of lead weight, length of branch lines, length of main line, number of hooks per basket, etc. Because of the limited number of sets done so far, analyses on the methodology of fishing are not attempted in this report.

It is hoped that the different factors which affect the availability and abundance and the best procedure in catching deep-swimming tuna may be determined in the course of this exploratory work.

On these technical trips, two biological assistants were on hand to gather not only the biological data of the catches but also to make plankton hauls with a Marutoku-B type nets and take hydrographic observations which were collected before and after the settings of the longline. The weight, length, maturity, conditions of the gonads, and other morphometric data of the tunas caught were taken and recorded following the techniques of Marr and Schaefer (1949), and the stomach contents and parasites were saved as well.

Bathythermograph casts were made at fishing stations during the second and third fishing cruises to determine the depth of the water at 23°C which appears to be the most favourable temperature for locating deep-swimming tuna. Some gonads recovered during these cruises have been saved and are being studied in detail for maturity and fecundity determination.

This report is based on the analysis of yellowfin tuna, Neothunnus macropterus (Temminck and Schlegel); bigeye tuna, Parathunnus sibi (Temminck and Schlegel); and a few albacore, Germo alalunga (Bonnaterre) which were caught during these cruises, comprising 63.62 percent of the total fish caught. Other fishes caught by longline were sharks, marlins, dolphins, swordfishes, sailfishes, lancet fishes, snake mackerels and barracudas. The following fishes caught which represent new records in the Philippines are snake mackerel, Gempylus serpens; three "pandawan", Lepidocybium flavobrunneum (Smith); and, some lancet fish, Alepisaurus sp. A leatherback turtle, Dermochelys coriacea Boulenger with a carapace length of 150 cm and 125 cm in width was accidentally caught by its flipper but was inadvertently released.

Figure 1 shows a comparison of length-frequency distribution of yellowfins taken by trolling and by longlining. The difference between the year classes available for the two methods of fishing is clearly shown.

Most fish taken by trolling were from 450 mm to 600 mm total length, whereas the fish available to the longline fishery vary from 1,050 mm to 1,850 mm total length and it is probable that the fishery depends upon several year classes.

In Table I may be seen the summary of the total catches made during the three fishing cruises of the M/V Malasugui in 1960.

During the three fishing cruises a total of 174 yellowfin tuna with an average of 136.59 cm in total length and average weight of 34.07 kilograms and 60 bigeye tuna with an average of 145.69 cm in total length and an average weight of 51.39 kilograms were caught. Eleven albacore were also caught near Davao, in the island of Mindanao.

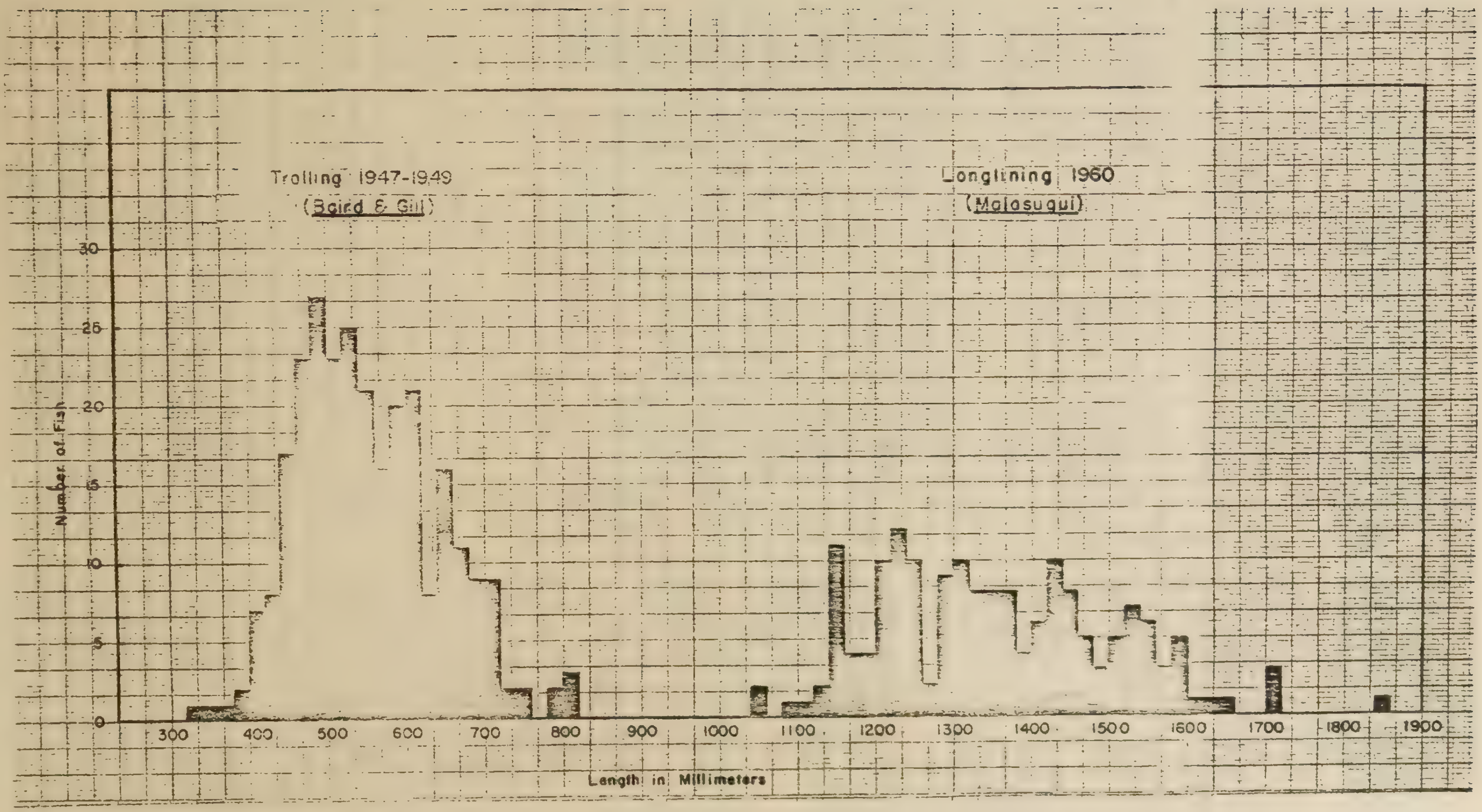


Figure 1. Comparison of length frequency distribution of Neothunnus macropterus taken in Philippine waters.

Table I

Summary of total catches made in three cruises of the M/V *Malasugui*, in 1960 in Philippine waters

Fishes	Number	Percent	Total wt (kg)	Percent	Mean wt
Yellowfin	174	45.19	6684.9	41.11	39.79
Bigeye	60	15.58	3368.3	20.71	56.14
Albacore	11	2.85	270.4	1.66	24.58
Blue Marlin	9	2.33	823.3	5.06	91.48
Swordfish	26	6.75	828.7	5.09	31.87
Sailfish	13	3.37	504.7	3.10	38.82
Sharks	64	16.62	3656.1	21.92	55.70
Miscellaneous	28	7.27	212.9	1.30	7.60

Yellowfin tuna predominates the catch both in number and weight. Although sharks make up a higher percentage of the catch than other tuna-like fishes both in number and weight, the combined percentages by number of all the tunas taken is 63.2 percent and by weight is 73.48 percent, indicating a high percentage of tunas available in Philippine waters through longlining. The marlin, sailfish and swordfish make up 12.45 percent by number and 13.25 percent by weight.

Based on mean weight by kind, it appears that blue marlins are the heaviest fish taken (91.48 kg), followed by bigeye (56.14 kg), and sharks (55.70 kg). The yellowfin, sailfish, and swordfish follow in descending order. The mean weight of albacore is 24.58 kg.

Table II is a summary of the pertinent data of the different species of tunas caught during each fishing cruise of the M/V Malasugui. Yellowfin predominates the catch in all three cruises and the similarities in their mean lengths and mean weights indicate that they probably belong to the same year class. This condition does not appear to be true in the case of bigeye. Those captured in the second cruise were comparatively larger (155.0 cm) than those caught during the first (132.72 cm) with a mean difference of 22.28 cm and almost twice as heavy with a mean difference of 25.36 kg. Only one albacore was caught during the first trip and another on the third trip. During the second cruise, nine albacores were taken. This, therefore, cannot be compared with those captured during the other trips.

2.1 Hook rate per 100 hooks

The hook rate per 100 hooks for the yellowfin (1.07) and the bigeye (1.02) were taken per trip and were almost identical in both species caught during the two cruises. The hook rates by species during the first cruise were almost the same for the yellowfin and the bigeye while those taken during the second trip of the yellowfin and the bigeye were less than 1. The hook rate by species of the yellowfin during the third trip was comparatively higher (1.61) than the first and second trips.

The hook rates for the three kinds of tuna taken per 100 hooks were high during the first trip (3.03) but low and similar during the second (1.99) and third trips (1.89).

To determine the possible movement of the deep-swimming tuna in Philippine waters, the sizes of the tuna caught are plotted against the fishing grounds (localities) of increasing latitudes (Figures 3 and 4).

There seems to be a very small trend of increase in size in the fish caught from the areas nearer the island of Luzon, supporting the theory that the fish follow the Equatorial Current to Celebes Sea and enter the Sulu Sea or between the islands for their northern migration through Philippine territorial waters. This condition apparently holds true with the surface-swimming yellowfin taken by trolling (Figure 2).

Table III gives a summary of the pertinent data per operation for the three species of tuna caught by the M/V Malasugui during the three longline cruises with the sex ratio and log book remarks.

During the three trips the surface water temperature was from 27.6°C to 29.10°C. There are still few thermocline data on the use of the bathythermograph to warrant a good conclusion at the moment.

It will be noted that the greatest catches were from Celebes Sea, Moro Gulf and the waters near Basilan Island. Around this island surface-swimming yellowfin tuna is caught by deep water traps from November to May while skipjack is taken by the same gear throughout the year.

Of the three exploratory cruises of the M/V Malasugui, there was more tuna caught during the first cruise (March to April) which is the tuna season in the Philippines, especially in the southern part of the archipelago where more tuna abounds than elsewhere in the country. During this cruise male yellowfin predominated, while there were slightly more female bigeye taken. The yellowfins had an average weight of 39.04 kg and were heavier than the bigeye tunas which averaged 28.83 kg.

It will be noted that one species predominates the catch of each operation, indicating the schooling behaviour of tunas. In Operation 1 of the first cruise, there were four bigeye tuna caught to one yellowfin; while in Operation 3, five tunas, all yellowfin were taken. During Operation 4, twelve yellowfin were taken. Male predominates at a ratio of 2 : 1. In Operation 5, nine yellowfin and four bigeye tuna were taken. Again the males

Table II

Summary of the pertinent data of the different species of tuna catches during the three exploratory long-line fishing cruises made by M/V Malasugui in Philippine waters in 1960.

Trip and date	No.	Length in cm		Weight in kg		Total weight kg	Average weight kg	Catch per hundred hooks	
		$\bar{x}$ + S E	o + S E	$\bar{x}$ + S E	o + S E			by species	all species
Yellowfin									
I - March 22 to April 10	87	132.08+1.69	15.78+1.19	30.50+.12	11.10+.84	2,225.8	29.04	1.07	3.03
II - June 18 to July 11	43	138.56+2.01	13.12+1.4	34.64+1.8	11.84+1.2	1.531.7	35.62	0.95	1.99
III - Sept. 22 to Oct. 16	34	141.80+4.5	26.49+3.2	33.16+1.6	9.54+1.16	1.123.4	33.04	1.61	1.89
Bigeye									
I	25	132.72+4.5	22.52+3.2	38.24+3.6	18.00+2.57	1.586.1	28.83	1.02	3.03
II	35	155.0+2.9	17.16+2.06	63.60+3.37	19.92+2.4	2.243.2	64.09	0.77	1.99
III	2	143.1		59.1		118.2	33.04	0.09	1.89
Albacore									
I	1	108.0		20.0		20.0	20.0	0.29	3.03
II	9	116.24+1.55	4.64+1.1	25.22+.58	1.74+.41	225.9	25.1	0.19	1.99
III	1	103.2		24.5		24.5	24.5	0.47	1.89

Table III

Summary of pertinent data for the three longline cruises of the M/V Malasugui (1960) in Philippine waters.

Trip I

Station No.	Date	Locality		Water Surface Temp. °C	Depth Thermocline (meters)	Yellowfin			Bigeye			Albacore			Remarks
		Latitude	Longitude			M	F	Und.	M	F	Und.	M	F	Und.	
M_1 - 1	3/22	Panay Gulf		27.6		0	0	1	0	0	4	0	0	0	Poor catch
M_1 - 2	3/23	"		28.4		0	0	0	0	0	0	0	0	0	Poor catch (plenty of sharks)
M_1 - 3	3/31	"		28.0		2	2	1	0	0	0	0	0	0	Poor catch
M_1 - 4	4/2	Moro Gulf		29.5		8	4	0	0	0	0	0	0	0	Good catch YF were dominant
M_1 - 5	4/3	"		29.1		6	0	3	2	2	0	0	0	0	Good catch of YF
M_1 - 6	4/4	"		-		5	5	3	1	0	0	0	0	0	Good catch of YF
M_1 - 7	4/5	"		29.1		7	2	2	0	0	0	0	0	0	Good catch; YF were dominant
M_1 - 8	4/7	Celebes Sea		-		5	1	2	1	0	0	0	1	0	Poor catch; plenty of sharks; Albacore pres.
M_1 - 9	4/8	"		28.12		5	3	3	1	4	2	0	0	0	Very good catch; mixture of YF & BE
M_1 - 10	4/9	"		28.0		10	9	0	2	2	0	0	0	0	Very good catch; YF were dominant; sharks pres.
M_1 - 11	4/10	"		28.6		5	3	1	2	4	1	0	0	0	Good catch even with the presence of sharks
					TOTAL	53	29	16	9	12	7	0	1	0	

Table III continued

Trip II

Station No.	Date	Locality		Water Surface Temp. °C	Depth Thermocline (meters)	Yellowfin			Bigeye			Albacore			Remarks
		Latitude	Long-itude			M	F	Und	M	F	Und.	M	F	Und.	
M_2 - 4	6/22	5°57.2'N S. Basilan	122°5.5'E	29.49	85	3	1	0	0	1	0	0	0	0	Poor catch
M_2 - 5	6/28	Mindanao Sea		29.20	90-100	2	0	0	0	0	0	0	0	0	Poor catch(plenty of sharks)
M_2 - 6	6/29	"		29.40	75-90	0	0	0	0	0	0	0	0	0	Poor catch(plenty of sharks)
M_2 - 7	6/30	"		29.40	-	4	0	0	1	0	0	0	0	0	Poor catch
M_2 - 8	7/8	Off Surigao		29.48	85-100	1	0	0	0	0	0	0	0	0	Poor catch
M_2 - 9	7/9	Off Davao Gulf		28.79	85-105	0	0	0	6	6	0	0	0	0	Good catch of large Bigeye; no sharks
M_2 - 10	7/10	"		29.53	100-120	2	2	1	9	8	0	0	0	0	Very good catch; mixture of BE & YF; no sharks
M_2 - 11	7/11	"		29.5	-	4	1	0	1	0	0	6	3	0	Good catch; albacores were dominant; some YF & only one BE
					TOTAL...	28	15	3	19	16	0	6	3	0	

Trip III

Station No.	Date	Latitude	Long-itude	Water Surface Temp. °C	Depth Thermocline (meters)	YF M	YF F	YF Und	BE M	BE F	BE Und.	Alb. M	Alb. F	Alb. Und.	Remarks
M_3 - 1	9/25	Panay Gulf		28.75	105-115	1	1	1	0	0	0	0	0	0	Poor catch
M_3 - 2	9/30	Moro Gulf		-	105-115	5	2	1	0	0	0	0	0	0	Poor catch; sharks present
M_3 - 3	10/1	"		29.20	100-115	5	3	1	0	0	0	0	0	0	Poor catch (mostly Yellow-fin tuna)
M_3 - 4	10/2	Illana Bay		28.7	-	2	1	0	0	0	0	1	0	0	Poor catch
M_3 - 5	10/9	Celebes Sea		27.8	-	11	3	0	1	1	0	0	0	0	Very good catch; no sharks; YF were dominant
					TOTAL...	24	10	3	1	1	0	1	0	0	

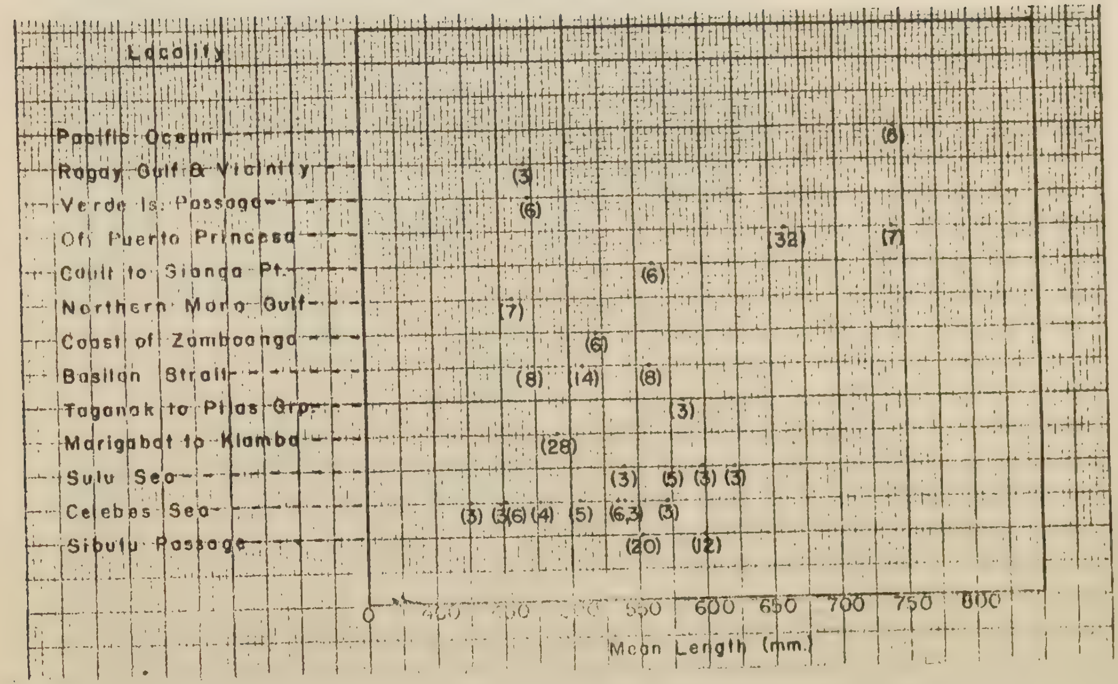


Figure 2. Size distribution of Neothunnus macropterus caught by trolling (Baird) 1947 - 1949 in Philippine fishing grounds.

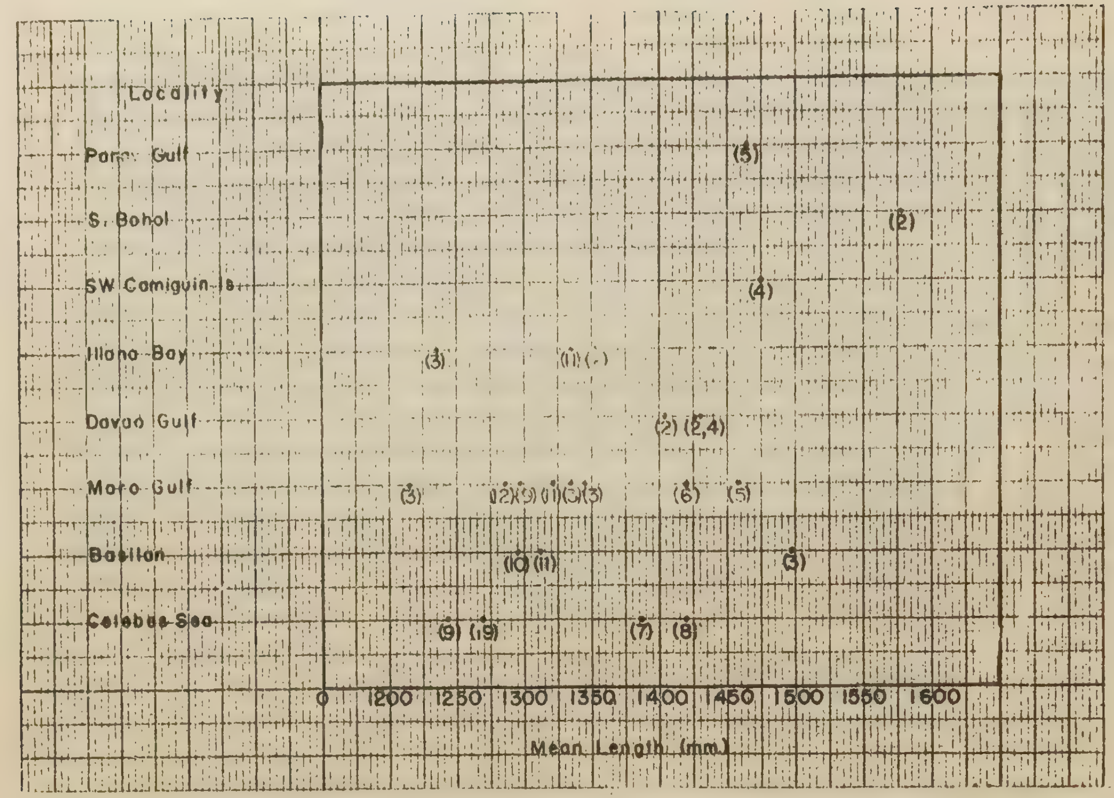


Figure 3. Size distribution of *Neothunnus macropterus* caught by longlining (*Malasugui*) 1960 in Philippine fishing grounds.

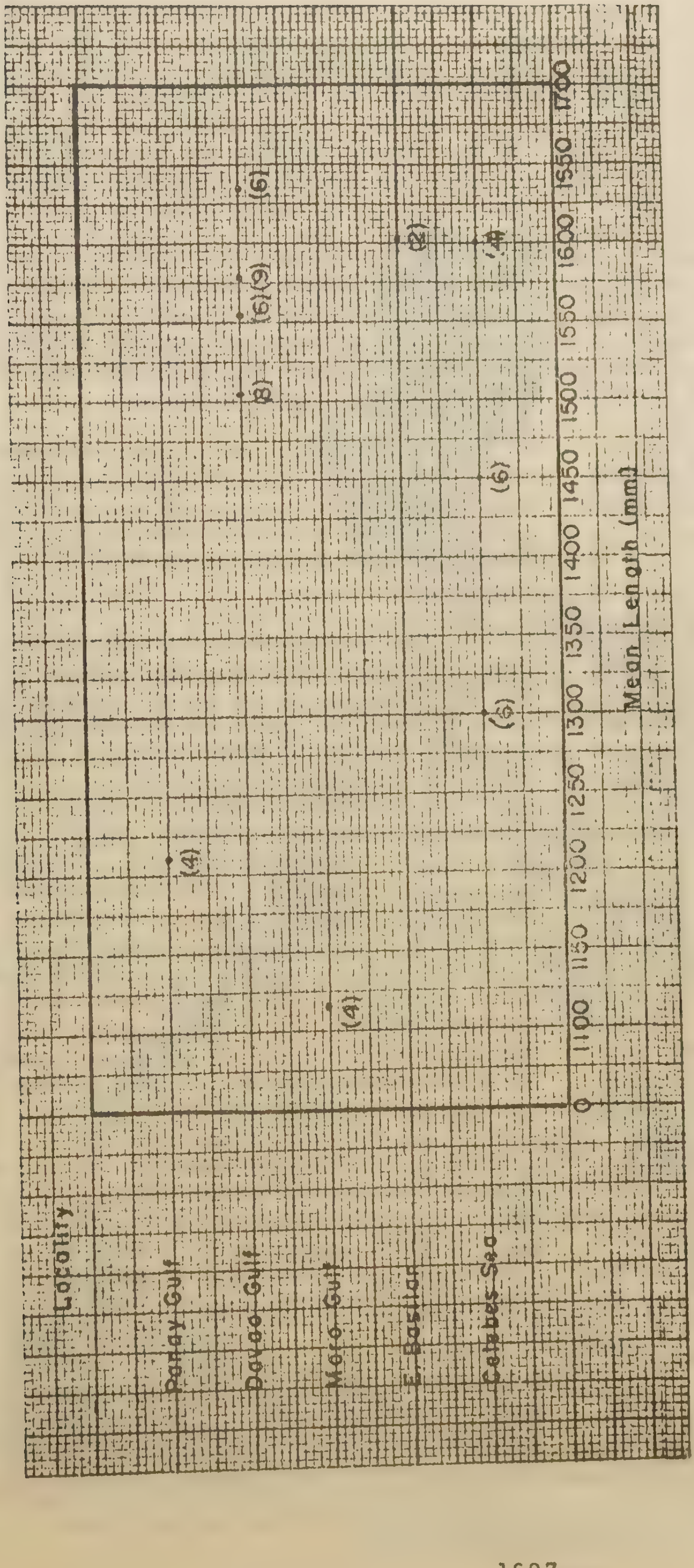


Figure 4. Size distribution of *Parathunnus sibi* caught by longlining (*Malasugui*) 1960 in *Philippine fishing* grounds.

predominate the catch more than 2 : 1. In Operation 6, thirteen yellowfin and one bigeye were taken; equal number of females to males were taken. All ovaries were unripe. In Operation 7, eleven yellowfin were taken. Again seven were males with a sex ratio of more than 3 : 1 in favour of the males. In operation 8, of the nine yellowfin, six were males. In Operation 9, eleven yellowfin, male predominating, and seven bigeye, mostly females were taken. Operation 10 yielded nineteen yellowfin and five bigeye, sex ratio was 1 : 1. Five fish (four yellowfin and one bigeye) were ripe. In Operation 11, out of sixteen tunas taken, nine were yellowfin. More male yellowfin were taken while in the bigeye females predominated. Three female yellowfin were ripe.

In the latter part of the trip (April) most females taken were either ripe or spent, indicating the spawning season for these species.

During the second cruise, a total of eleven operations were productive. Of this number, however, only six operations, i.e., Operations 3, 4, 7, 9, 10 and 11, had catches of more than five fish each. During Operation 3 at eastern Basilan, twenty-two yellowfin and three bigeye tunas were taken, the sex ratio for yellowfin being 1 : 1. Both immature and mature fish were found in the catch. Operations 4 and 7 yielded five fishes each of which four were yellowfin and one bigeye.

Operation 9, off Davao Gulf, is interesting for twelve specimens, all bigeye tuna, were taken. Almost all the females were mature. Sex ratio was 1 : 1.

Operation 10, also off Davao, yielded seventeen bigeye and five yellowfin. Sex ratio was 1 : 1 in both species. Most females were mature.

In Operation 11, out of fifteen tunas taken, five were yellowfin and nine albacores. Sex ratio for the yellowfin was 4 males to 1 female; for the albacore 1 : 1. Again the schooling behaviour of these fish was very apparent. Both the yellowfin and albacore taken were mature.

During the third cruise five productive operations were made but only Operations 2, 3 and 5 netted more than five fish each. Operation 2 yielded all yellowfin tuna most of which were maturing. Sex ratio was 2 : 1. In Operation 3 at Moro Gulf, eight yellowfin were taken. In both operations more males were taken (2:1). The three females were still in the maturing stage. In Operation 5, out of sixteen tunas taken, fourteen were yellowfin. Males predominated by 3 : 1. The males were mostly maturing while the females were immature. Again the catch indicates the schooling behaviour of the fish which are of the same maturity and size range.

Figures 5, 6 and 7 show the routes taken by the M/V Malasugui during its three exploratory cruises. The shaded portions of the routes show the areas where successful settings had been made together with numbers indicating the catch ratio on tunas per hundred hooks.

It will be noted that the successful fishing areas were along the coasts in such areas where previous longline operation had been proved successful. Moro Gulf and Celebes Sea, especially in the vicinity of Basilan Island, are very productive.

Near Davao Peninsula at the approach of Davao Gulf a few albacores were taken. This fish appears to follow the North Equatorial Current and a few stragglers are diverted south following the Equatorial Counter Current towards the island of Mindanao and are caught in Davao area. The majority of the fish probably move up toward Japan following the Kuroshio Current. This fishery is worth exploiting on the eastern side of the Philippines. Due to the absence of systematized fishing for tuna on the Pacific side of the Philippines, records are wanting on the migration path of this fish. It is known, however, that albacores are taken in the Bicol region of southern Luzon by sustenance fishing. Martin (1938) recorded the Japanese methods of fishing for surface-swimming tuna by pole and line and for deep swimming tuna by longline in this area.

Tapiador (1951) gives a summary of the tuna hook rate (catch per hundred hooks). There is a very close relationship between the localities where longline operations have been proved successful previous to the present exploratory cruises of the M/V Malasugui.

Tables IV and V give for each operation of the M/V Malasugui the mean lengths and weights, their standard deviations, standard errors and sexes of yellowfin and bigeye tuna respectively, taken by longline. The range in sizes, among the yellowfin indicates the probability that the fish belong to one or at most two age groups.

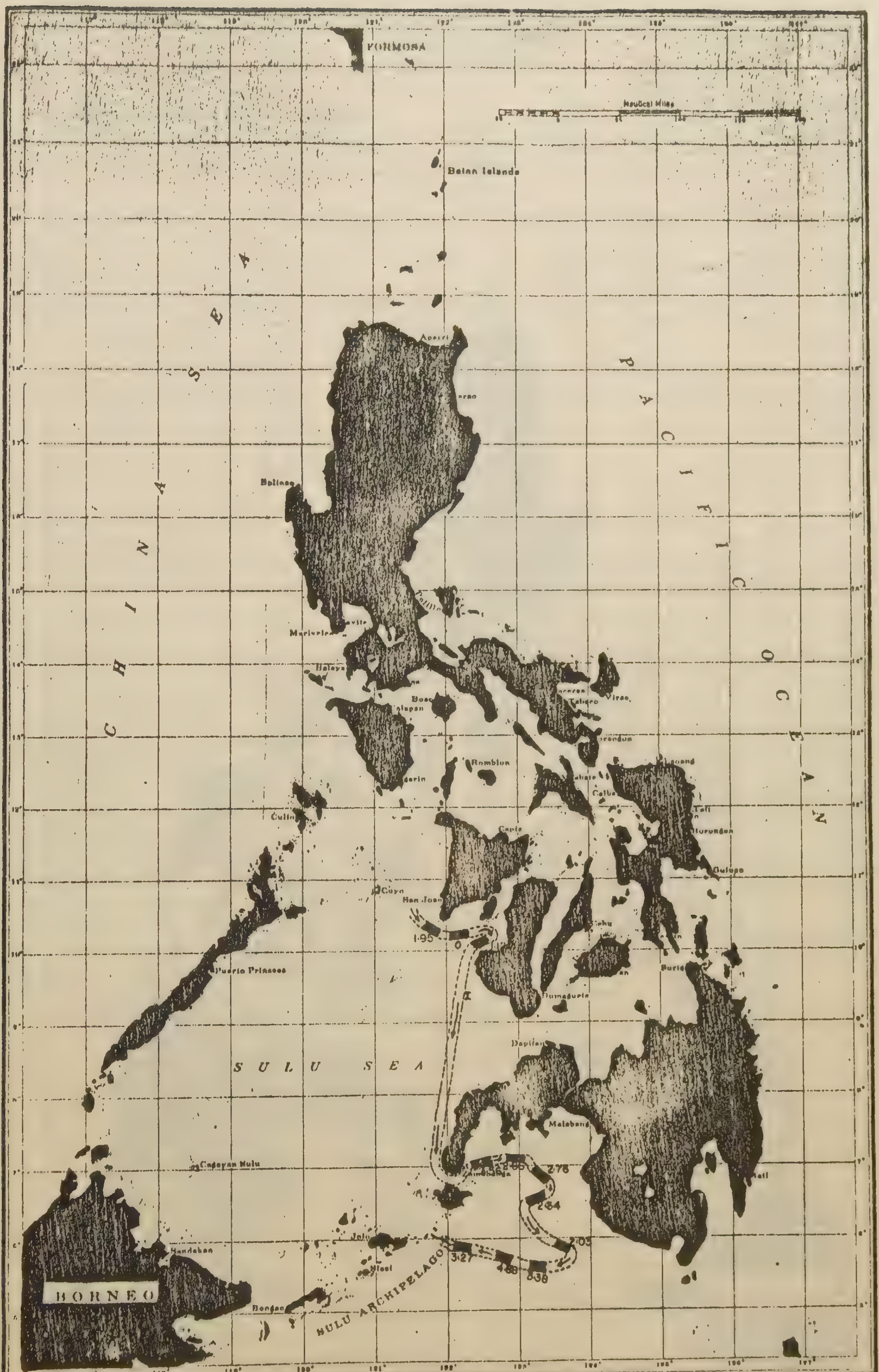
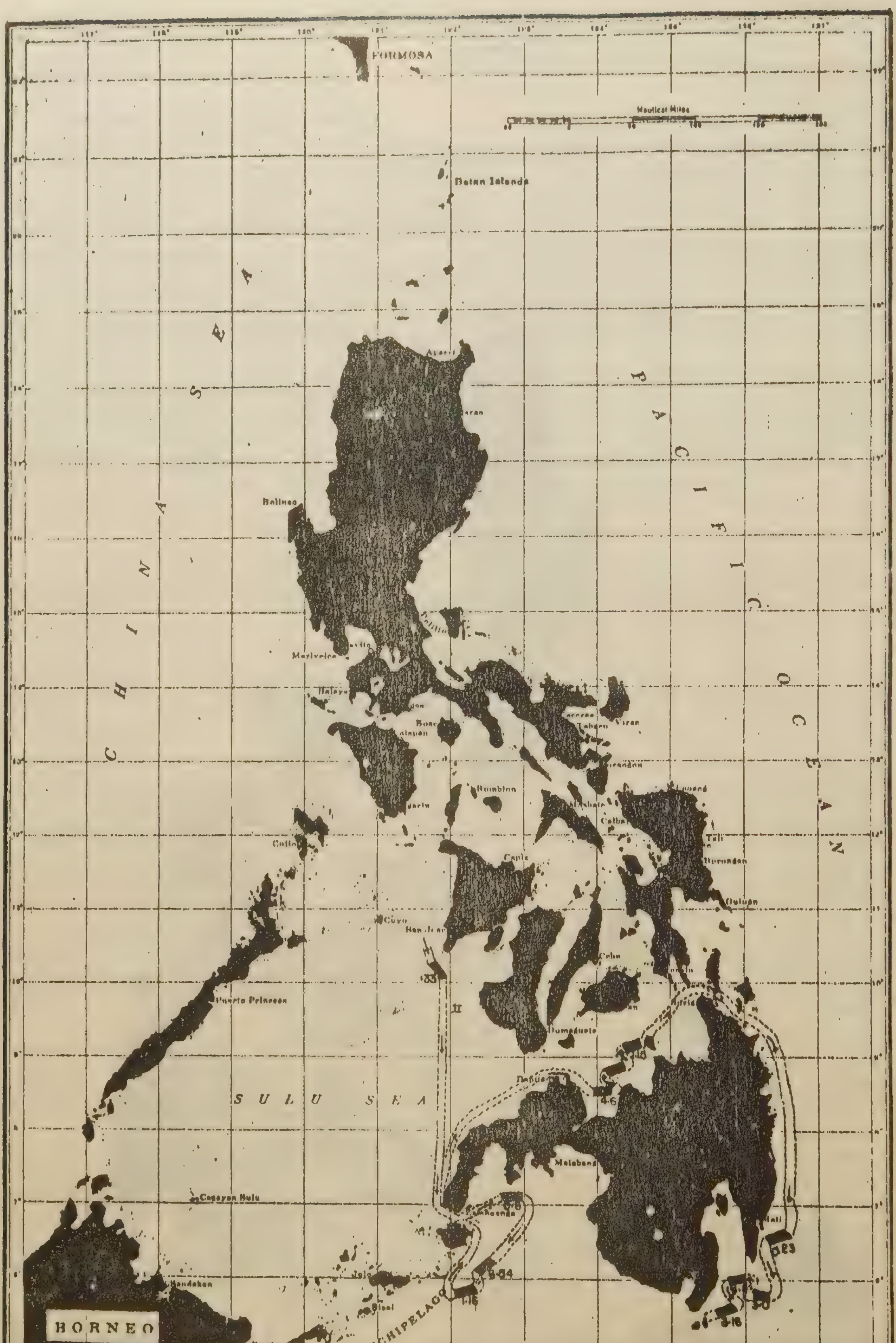

FORMOSA
Nautical Miles
Batan Islands
Aparri
Bolinao
Mariveles
Cavite
Calapan
Romblon
Culion
Cuyo
San Jose
Puerto Princesa
Dumaguete
Dapitan
Malabang
Cagayan Sulu
Jolo
Siasi
Sandakan
Bongao
BORNEO
SULU ARCHIPELAGO
SULU SEA
CHINA SEA
PACIFIC OCEAN
1.95
0
2.76
2.64
2.05
3.27
4.88
6.38

Figure 5. Routes of the first cruise of M/V Malasugui (1960)
Tuna Fishing Exploration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Batan Islands
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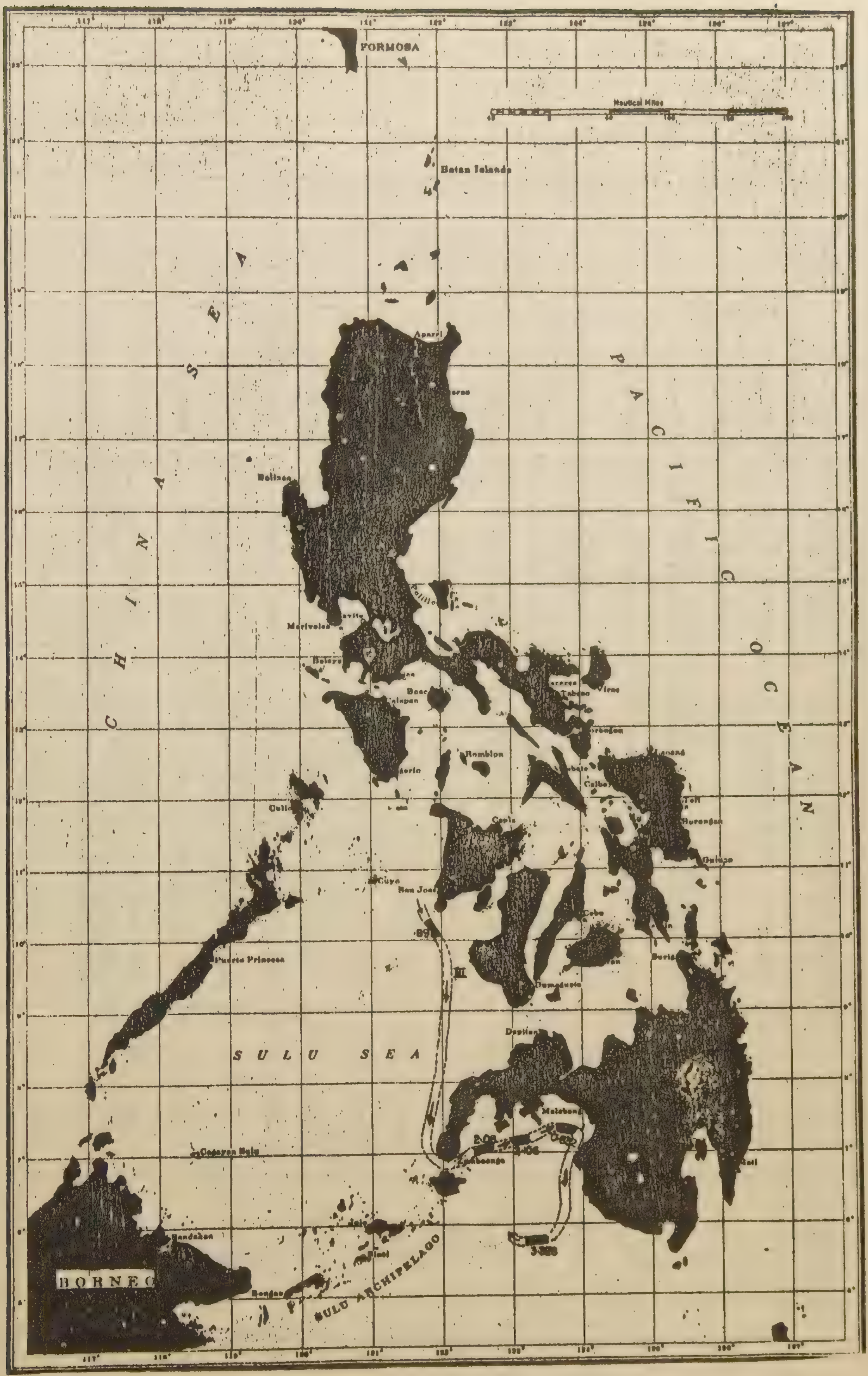
Bolinao
Mariveles
Romblon
Capiz
Cuyo
Cebu
Puerto Princesa
Dumaguete
Dapitan
Malabang
Cagayan Sulu
Zamboanga
Jolo
Sandakan
BORNEO
SULU ARCHIPELAGO
CHINA SEA
SULU SEA
PACIFIC OCEAN

Figure 6. Routes of the second cruise of M/V Malasugui (1960) Tuna Fishing Exploration


FORMOSA
Nautical Miles
Batan Islands
Aparri
CHINA SEA
PACIFIC OCEAN
Bolinao
Polillo
Mariveles
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Balayan
Calapan
Tabaco
Virac
Romblon
Sorsogon
Calbayog
Catbalogan
Tolosa
Capiz
Culion
Cuyo
San Jose
Cebu
Surigao
Puerto Princesa
Dumaguete
Dapitan
SULU SEA
Malabang
Zamboanga
Cagayan Sulu
Sandakan
BORNEO
Siasi
Bongao
SULU ARCHIPELAGO
III
2-03
2-106
5-623
3-326

Figure 7. Routes of the third cruise of M/V Malasugui (1960) Tuna Fishing Exploration

Table IV

Mean lengths and weights, their standard deviations, standard errors and sexes of yellowfin tuna taken by longline by the M/V Malasugui (1960) per operation.*

Trip and Operation	Date	Length in cm		Weight in kg		Sexes	
		$\bar{x}$ + S E	o + S E	$\bar{x}$ + S E	o + S E	M	F
I - 3	March 31	146.4+14.86	23.92+7.71	43.0+7.45	14.9+5.32	2	2
- 4	April 2	128.5+4.67	15.9+3.24	36.0+3.17	10.8+2.21	8	4
- 5	April 3	142.0+6.40	15.36+4.62	37.32+3.76	9.04+2.65	6	0
- 6	April 4	132.2+3.89	12.84+2.73	31.92+2.57	9.48+2.01	5	5
- 7	April 5	129.6+4.46	13.38+3.18	28.32+3.62	10.86+2.58	7	2
- 8	April 7	138.6+5.86	15.24+4.12	33.0+2.59	9.60+2.59	6	1
- 9	April 8	124.3+3.36	10.08+2.40	24.44+2.12	6.36+1.51	5	3
-10	April 9	126.9+3.25	14.0+2.29	27.08+2.12	9.12+1.49	10	9
-11	April 10	142.0+4.28	12.0+3.00	35.48+2.24	6.28+1.57	5	3
II - 3	June 21	130.8+2.09	9.2+1.46	27.2+1.36	6.0+ .95	10	10
- 4	June 22	147.0+2.58	5.16+1.84	38.0+3.00	6.0+2.14	3	1
- 7	June 30	148.0+3.60	7.2+2.57	46.0+5.20	10.4+3.71	4	0
-10	July 10	141.0+1.58	3.16+1.13	35.5+1.47	2.94+1.05	2	2
-11	July 11	142.0+2.00	4.4+1.42	38.4+ .89	1.96+ .63	4	1
III - 2	Sept. 30	127.8+8.65	22.5+6.08	29.52+2.21	13.56+3.66	5	2
- 3	Oct. 1	141.0+3.61	10.12+2.53	34.48+2.98	8.36+2.09	5	3
- 5	Oct. 9	131.61+3.23	11.94+2.24	30.00+2.19	8.12+1.53	11	3

*Only catches of 4 or more were included

Table V

Mean lengths and weights, their standard deviations, standard errors and sexes of bigeye tuna taken by longline by the M/V Malasugui (1960) per operation.*

Trip and Operation	Date	Length in cm		Weight in kg		Sexes	
		$\bar{x}$ + S E	o + S E	$\bar{x}$ + S E	o + S E	M	F
I - 1	March 22	121.0+4.32	17.3+6.17	26.0+6.92	13.84+4.92	-	-
- 5	April 3	111.50+2.38	4.76+1.70	19.6+ .56	1.128+ .40	2	2
- 9	April 8	130.0+6.60	15.72+4.62	36.98+4.47	10.74+3.16	1	4
-10	April 9	160.5+7.44	14.88+5.31	62.0+6.92	13.84+4.94	2	2
-11	April 10	145.02+5.87	14.10+4.14	42.68+4.11	9.88+2.91	2	4
II - 9	July 9	160.16+5.29	18.00+3.67	71.83+6.62	22.5+4.59	6	6
-10	July 10	153.65+3.27	13.44+2.32	62.82+3.48	14.28+2.46	9	8

*Only catches of 4 or more were included.

2.2 Food habits

The purpose of the food-study investigation of the deep-swimming tunas was to determine which animals were important to the diet of these fish and to determine whether differences exist in the food composition and feeding habits between yellowfin and bigeye tuna. This knowledge may permit extensive research in the distribution of such food organisms in the various fishing grounds and in the distribution of the tunas.

The diets of the yellowfin tuna and the bigeye tuna caught by the research vessel M/V Malasugui during the three exploratory fishing cruises are reported. The following procedure was taken:

The stomachs are removed as soon as possible after the tuna comes aboard the ship, although it takes sometime before the fishes are dissected. The opened stomachs with their contents are put in a plastic bag with 5 percent formalin. In some cases where the contents are almost negligible, only an inventory of the stomach contents are taken.

At the laboratory, the stomachs and contents are soaked in fresh water for a few hours before they are separated from each other. The food items are separated into groups according to kinds of organisms. Identifications are made as closely as practicable and the number of each species or group of the organisms present is recorded.

The bait fish used, bañgos, Chanos chanos Forskal was included in this analysis. It appears that, in most cases, the bait fish has been digested and could no longer be recognized.

In the future a more detailed study will be made during the continuation of the longline fishing survey.

Table VI shows a summary of the total number of both yellowfin and bigeye tuna stomachs examined and the number of stomachs found empty in each species.

Table VII shows a list of important food groups found in the stomachs of 109 yellowfin and 15 bigeye with the frequency of occurrence and total number occurring of a particular food organism in number and percent.

Many of the fish remains recovered were unidentifiable; nevertheless, most of the fish recovered were pelagic forms, mostly carangids, snake mackerels and cutlass fish while there seems to be no preference among species of the plectognaths. Of the molluscs, the squids are most favoured, and of the crustaceans, the dacapods are well represented.

Among the bigeye, due to small number of stomachs examined, only preliminary conclusions can be made. Squids are the most favoured food among the molluscs, and no particular fish group is preferred. Of the crustaceans, the decapod larvae are taken more than all the others. It was noted that the trematode, Hirudinella ventriculosa (Pallas), was quite common in both yellowfin and bigeye tunas examined. Sixty specimens of this trematode were recovered from twenty-eight yellowfin and five bigeye tuna stomachs.

Figure 8 shows the food items (in percent) of the yellowfin tuna determined on the basis of numbers found in their stomachs Almost one-third of the food of yellowfin are fishes, but rapid digestion prevents further identification of most fishes. About two-thirds of the food are invertebrates and are mostly squids, stomatopods and crustacean decapods.

Figure 9 shows the food items (in percent) of the bigeye tuna. This species feeds more or less on the same major groups both of fishes and invertebrates as the yellowfin although on a more varied form but on more or less equal number. The small number of stomachs examined of this fish has to be considered.

Figure 10 shows the food items (in percent) of both the yellowfin and bigeye tuna combined. The similarity of the percentages of the food items between the species is very apparent.

Fish forms more than one-third and the molluscs, especially squids, form the last third of their food.

2.3 Gill raker counts

During the 1st and 2nd cruises the first gill arch on the right side of the fish were removed from the yellowfin and bigeye tunas and the number of gill rakers in the upper and lower arches as well as their totals were taken.

Table VI

Number of yellowfin and bigeye stomachs recovered from longline fishing operations of the M/V *Malasugui* in Philippine waters.

Trip	Yellowfin			Bigeye		
	w/contents	empty	total	w/contents	empty	total
I	55	3	58	10	3	13
II	30	2	32	4	4	8
III	24	10	34	1	1	2
Total	109	15	124	15	8	23

Table VII

Food classes consumed by yellowfin and bigeye tuna caught by longline by M/V *Malasugui* (1960) in Philippine waters, their frequencies of occurrence and total number occurring in number and percent

	Yellowfin 109*			Bigeye 15*		
	No. of stomachs in which items occurred		Total organisms occurring	No. of stomachs in which items occurred		Total organisms occurring
	Number	Per Cent		Number	Per Cent	
Fishes						
Percomorphi	37	33.9	68	2	13.3	4
Plectognathi	12	11.0	20	1	6.7	9
Bañgos remains (bait fish)	15	13.8	15	2	13.3	2
All others (Hemiramphids, flying fish, sardines)	4	3.7	6	-	-	-
Unidentified fishes	65	59.6	356	3	40.0	11
Fish remains	15	13.8	33	2	13.0	2
Mollusks						
Cephalopoda	70	64.2	323	6	40.0	11
Gastropoda	1	.9	1	1	6.7	1
Crustaceans						
Stomatopoda	26	23.9	200	1	6.7	6
Decapoda	64	58.7	178	4	26.7	10
Amphipoda	21	19.3	28	3	20.0	6
Other crustacea (Isopoda, copepods) etc.	4	3.7	5	-	-	-
Tunicates	5	4.5	11	1	6.7	3
Hirudinella ventriculosa	28	25.7	42	5	33.3	18
Unidentified nematods	6	5.5	23	4	26.7	5

*Number of stomachs examined

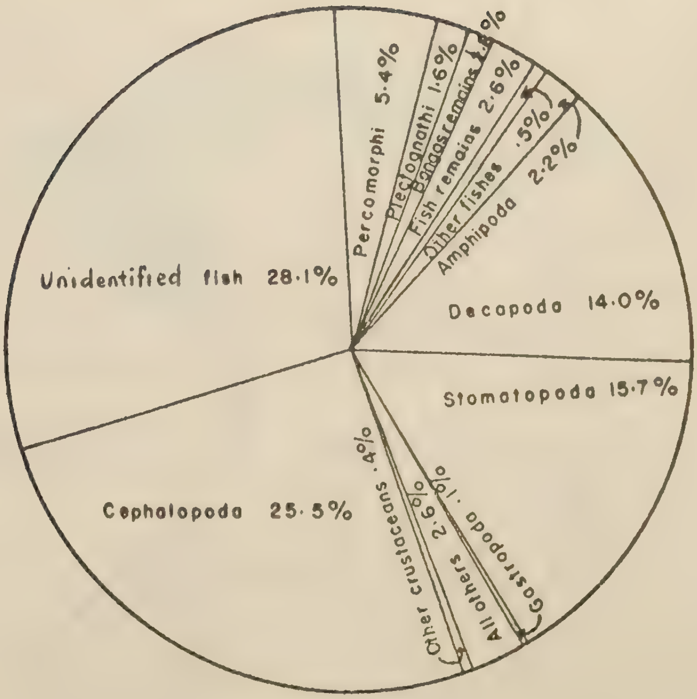

Figure 8. Percentage of food items of Neothunnus macropterus caught by longlining (Malasugui) 1960 determined on the basis of numbers found in the stomach.

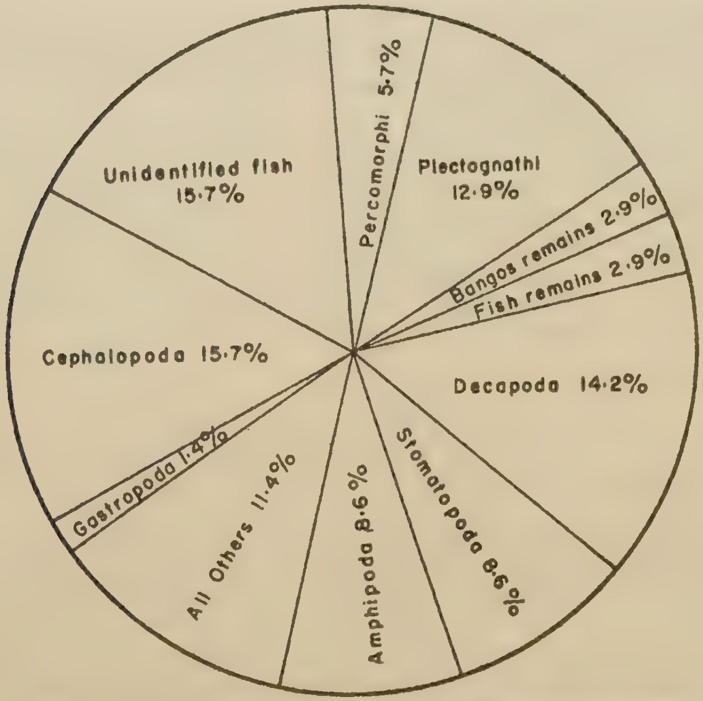

Figure 9. Percentage of food items of Parathunnus sibi caught by longlining (Malasugui) 1960 determined on the basis of numbers found in the stomach.

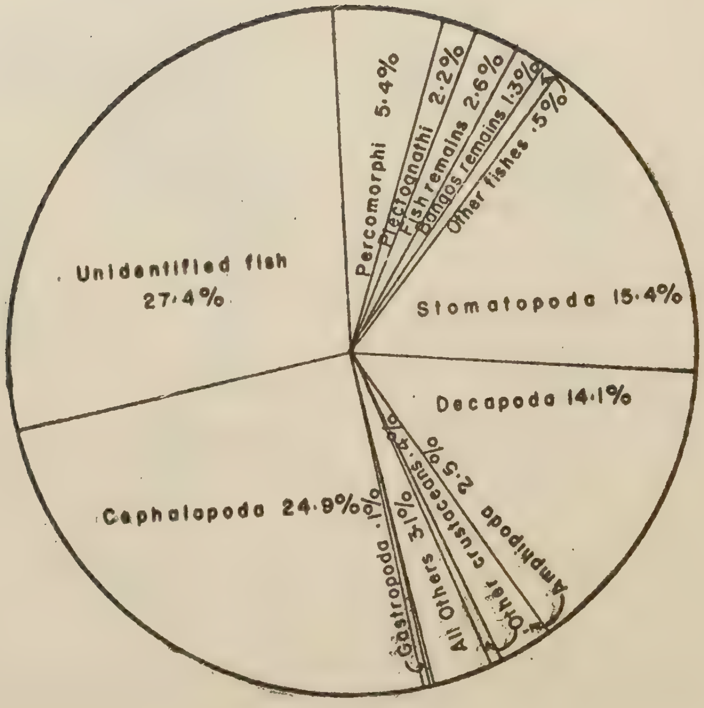

Figure 10. Percentage of food items of Neothunnus macropterus and Parathunnus sibi caught by longlining (Malasugui) 1960 determined on the basis of numbers found in the stomach.

Table VIII shows the summary of the gill raker counts in the upper and lower arches and their totals for the 66 yellowfin and 18 bigeye tuna, together with their mean numbers, standard deviations and standard errors. The mean value for the number of gill rakers for the upper arch is 8.94 and for the bigeye 8.65. For the lower arch, however, the mean value for the yellowfin is 20.27 while it is only 18.61 for the bigeye. The difference therefore in the number of gill rakers between the yellowfin and bigeye tuna is in the number of gill rakers in the lower arch.

On the total gill raker counts the mean value for the yellowfin is 29.21 while for the bigeye it is 27.29.

The fact that the total gill raker count from the yellowfin is very close to the value found by Schaefer (1952) which is 29.66 for those in the Hawaii area shows that this character is a very good criterion for determining relationship of this fish. It appears constant among the species.

2.4 Length-weight relationship

This important relationship indicating the growth of fishes was computed for the first time for Philippine tunas. Assuming that (W) is proportional to volume, the basic formula can be written $W = kL^x$ in which L represents length, k a constant and x a power closely approximating 3. The values for k and x were determined by the method of least squares for the bigeye and yellowfin tunas. Data for each fish (weight in kilograms and length in mm) were used. The logarithms of natural numbers were used in the mathematical operations and the logarithms of weight and total length were plotted for the yellowfin and bigeye tunas.

2.4.1 Yellowfin tuna

The logarithms of weight and total length are shown plotted in Figure 11.

The regression lines of log weight on log total length were calculated by the method of least squares. The regression coefficients were 2.85 for the males and 2.87 for the females. The graphic representation shows that the lines fit the data indicating that the log weight and log length of the yellowfin have a relationship that is very nearly a straight line.

The antilog equations of the weight-length curves for the two sexes were found to be for the 99 males, $W= 0.00002352\ L^{2.84682}$ and for the 43 females, $W= 0.00004322\ L^{2.87651}$. The weight-length data are shown plotted in Figure 12 and the curves are drawn using the above equations. The very slight differences between the k values and of the regression coefficients indicate that for a given size the two sexes do not differ appreciably in weight.

2.4.2 Bigeye tuna

Logarithms were also used in the mathematical computations of the length-weight relationships. The logarithms of weight and total length are shown plotted in Figure 13. The regression lines of log weight on log total length were calculated by the method of least squares. The regression coefficients were 2.94 for the males and 2.74 for the females. The graphic representation shows that the lines fit the data indicating that the log weight and log length of the bigeye tuna have a relationship that is also very nearly a straight line.

The antilog equations of the weight-length curves for the two sexes were found to be for the 27 males, $W = 0.00004786\ L^{2.94430}$ and for the 28 females, $W = 0.00001721\ L^{2.74669}$.

The weight-length data are shown plotted in Figure 14 and the curves are drawn using the above equations. The slight differences between the k values and of the regression coefficients indicate that although a slight difference in the weight of the fish is noticeable between the sexes in the smaller fish, as the fish matures from 1520 mm total length there is no appreciable difference in weight.

3 SURFACE SWIMMING TUNAS CAUGHT BY TROLLING

3.1 Previous studies done

The tuna available for this part of the study were taken by surface trolling gear which was described by Warfel (loc. cit.).

This method of trolling employs nine lines, six attached to two long bamboo poles extending outward, one on each side and three from the stern of the vessel. Trolling was carried out

Table VIII

Gill raker counts of yellowfin and bigeye tunas caught by M/V Malasugui (1960) in Philippine waters, their means, standard deviations and standard errors.

No. of gill rakers	Yellowfin 66*			Bigeye 18*		
	upper arch	lower arch	total	upper arch	lower arch	total
8	10			7		
9	51			10		
10	4			1		
11	1			-		
17		1			3	
18		2			7	
19		11			4	
20		21			2	
21		26			2	
22		5			-	
25			-			2
26			2			4
27			4			6
28			11			2
29			19			2
30			22			1
31			7			1
32			1			-
$\bar{x}$ + S E	8.94+0.14	20.27+0.12	29.21 0.15	8.67+0.14	18.61+0.28	27.27 0.37
o + S E	0.52+0.04	1.01+0.17	1.23 0.11	0.58+0.05	1.21+0.21	1.59 0.27

* Number of specimens examined.

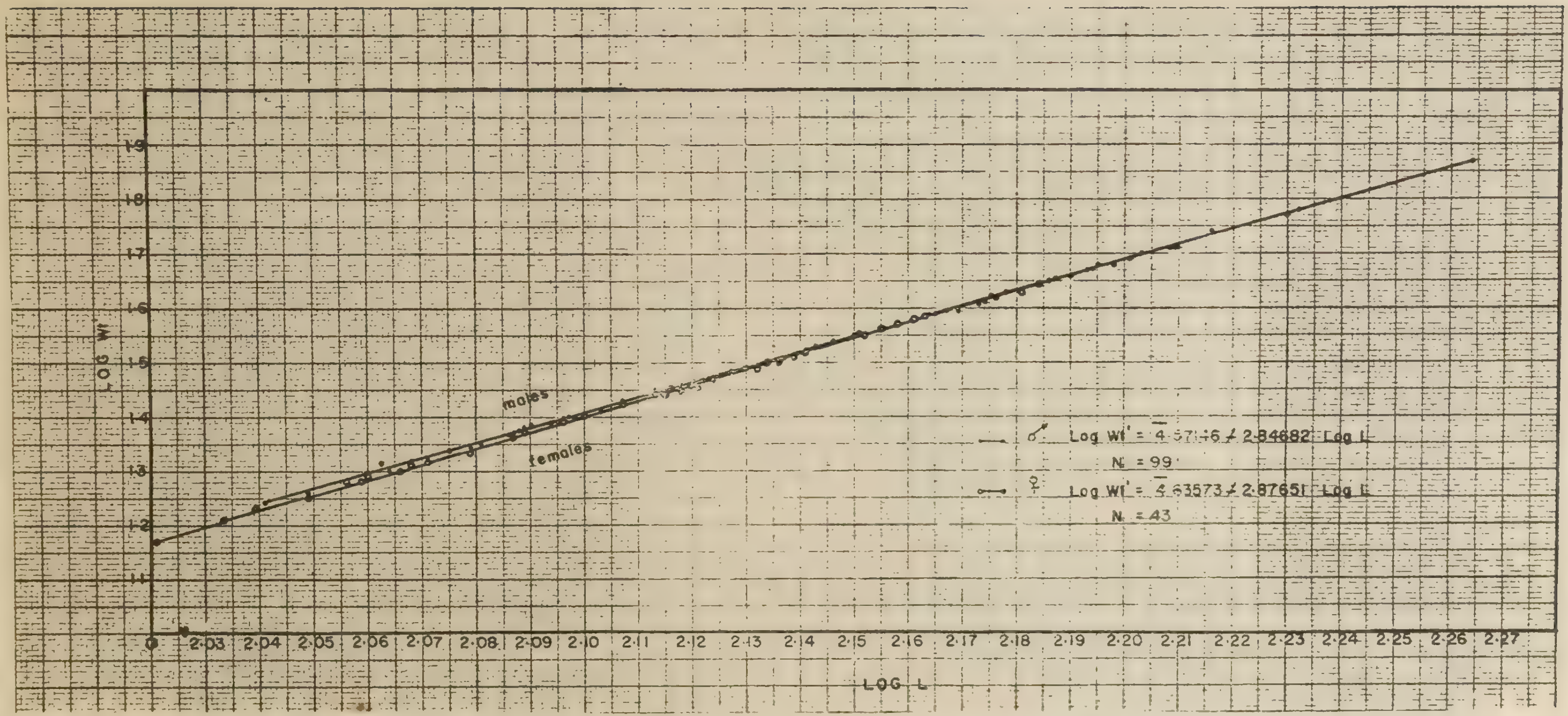

Figure 11. Regression of weight on length of Neothunnus macropterus caught by longlining (Malasugui) in Philippine waters in 1960.

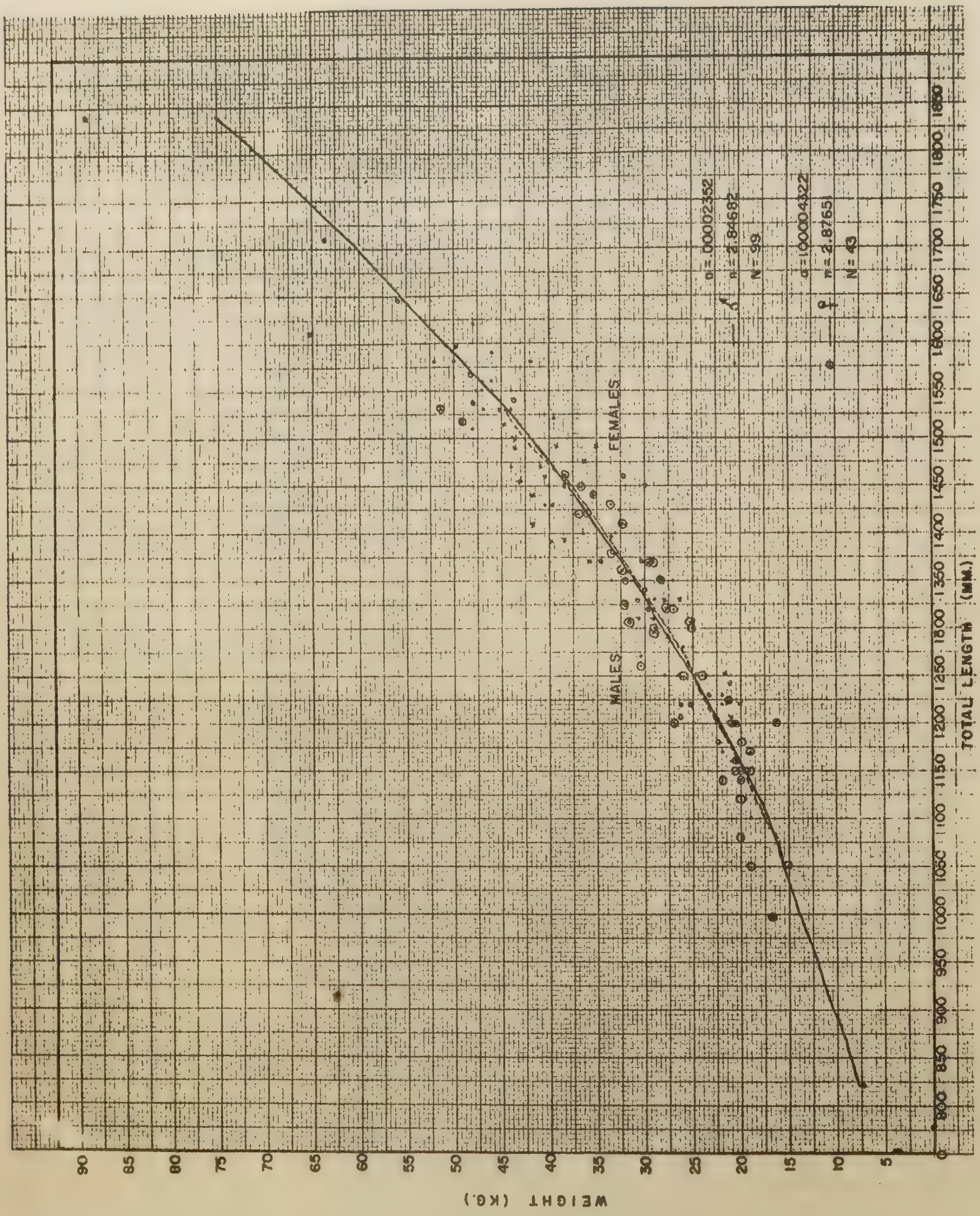

Figure 12. Length-weight relationship of Neothunnus macropterus from the Philippines caught by longlining (Malasugui) 1960.

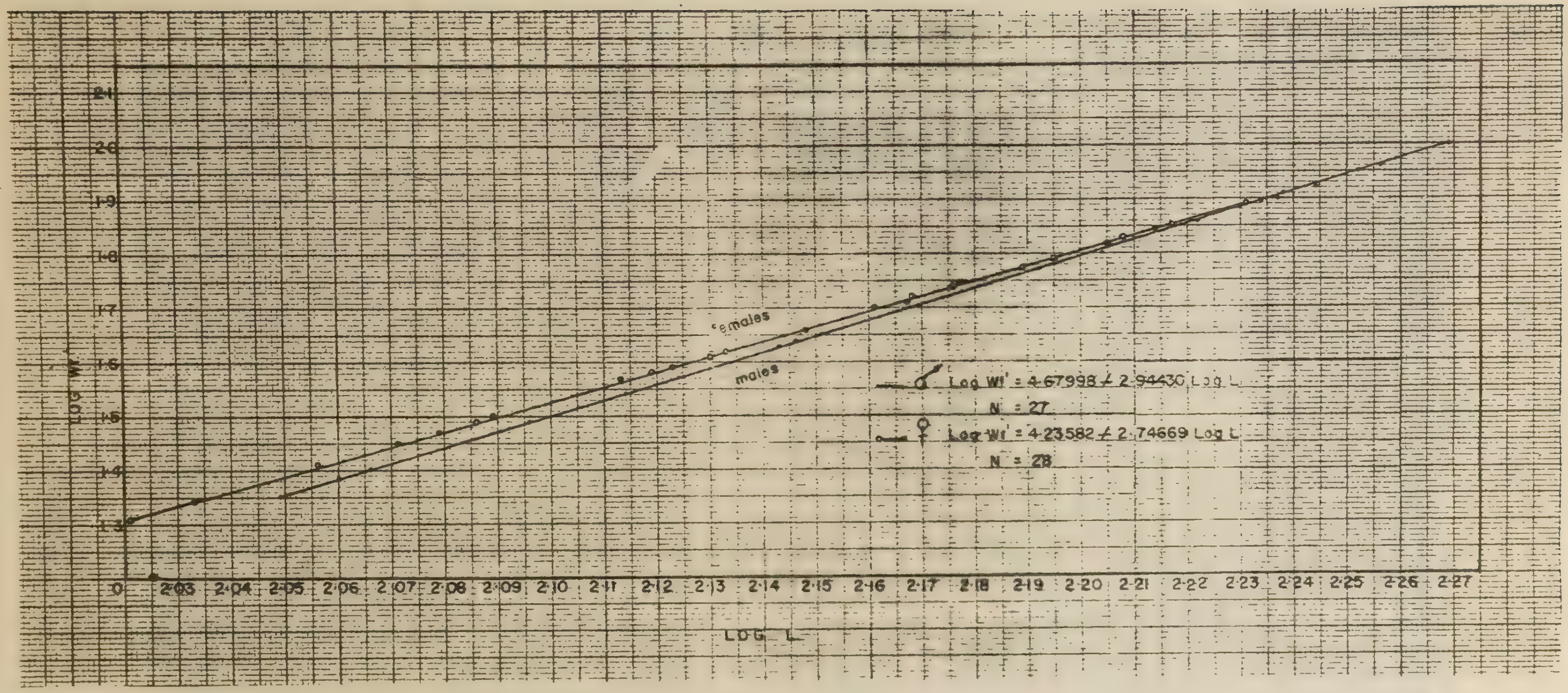

Figure 13. Regression of weight on length of Parathunnus sibi caught by longlining (Malasugui) in Philippine waters in 1960.

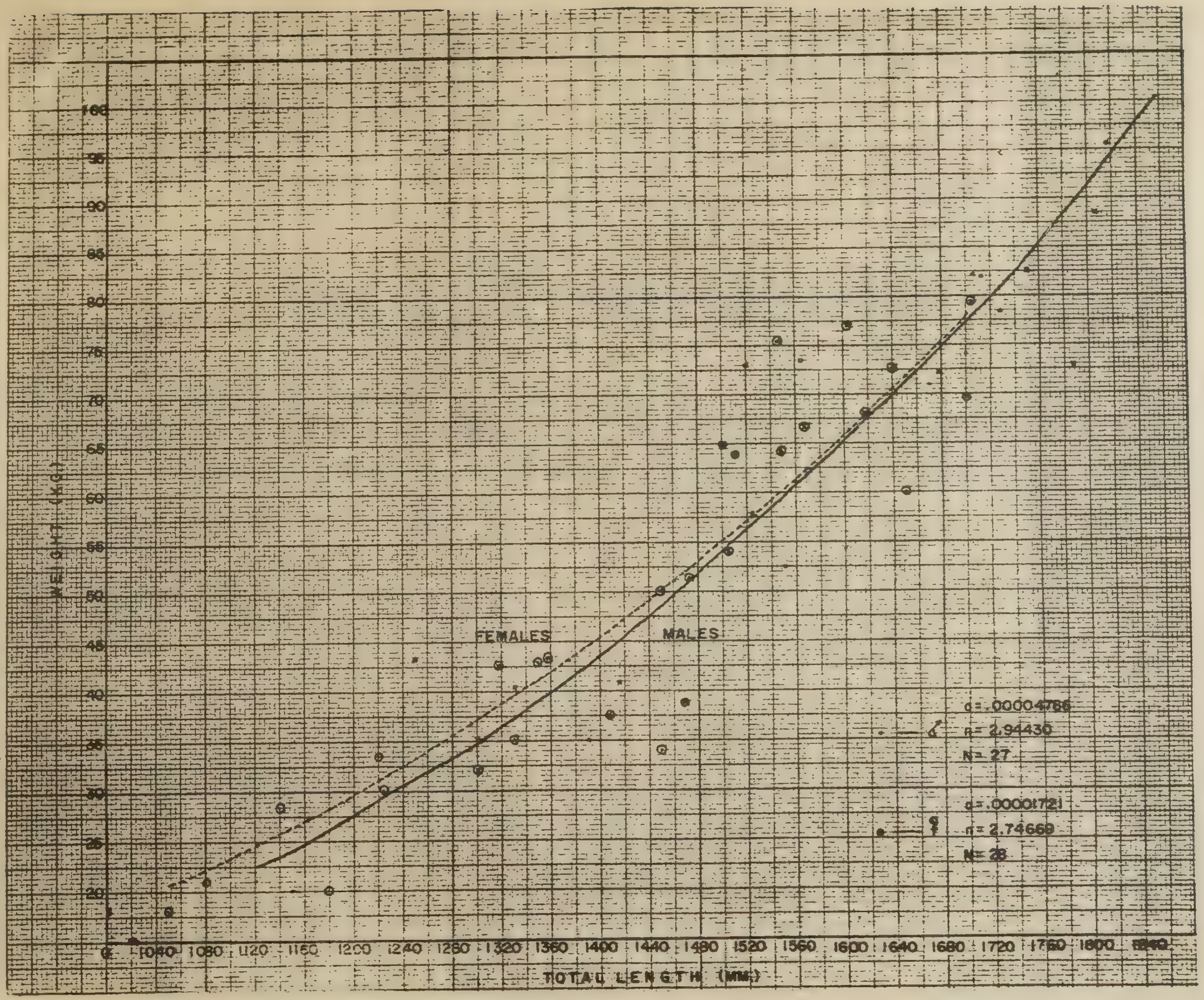

Figure 14. length-weight relationship of Parathunnus sibi from the Philippines caught by longlining in 1960 (Malasugui)

with an approximate speed of 7 to 9 knots from sunrise to sundown, when cruising to and from fishing grounds or when cruising from one oceanographic station to another by the following research vessels of the Philippine Fishery Program of the U.S. Fish and Wildlife Service from 1947 through 1949: the Spencer F. Baird, Theodore N. Gill, and David Starr Jordan.

Warfel (loc. cit.) described the different tuna and tuna-like fishes relatively common in Philippine waters and possibilities for development of a tuna industry. This also included a history of Philippine tuna fishery starting in 1920 when Japanese, Taiwanese and Okinawan fishermen were recorded fishing in Philippine waters. Wade (1950 b) described the spawning activities of Philippine tunas based on the same materials. Ronquillo (1953) reported on the food and feeding habits of yellowfin, skipjack and yaito tuna taken during these exploratory fishing cruises. Buñag (1956) described the spawning habits of the Philippine tunas based on the diameter frequency measurement of ovarian eggs partly from specimens by trolling operation by the above-mentioned exploratory vessels.

3.2 The different species of tuna now being reported are :-

1. Yellowfin tuna, Neothunnus macropterus (Temminck and Schlegel).
2. Skipjack, Katsuwonus pelamis (Linnaeus).
3. Yaito tuna or little tuna, Euthynnus yaito (Kishinouye).
4. Dogtooth tuna, Gymnosarda nuda.
5. Scaly tuna, Kishinoella tonggol (Bleeker).

Table IX shows a summary of the different species of tunas caught by trolling by these research vessels. The catches were biologically examined and the data were recorded upon capture but were not statistically treated until recently. The data on these fishes were originally transferred on columnar pad from the raw data. Lately, pertinent data per fish were transferred on index cards. These cards were readily sorted for statistical analysis.

Length measurements in mm were made on measuring boards and weights were taken in pounds on a Geedes scale.

Figure 15 shows the length-frequency distribution of skipjack caught by trolling. The size distributions of the yaito tuna (Figure 16) and that of the skipjack show marked similarity, i.e., the range for the skipjack is from 350 mm to 660 mm total length, while for the yaito tuna it is between 350 mm and 685 mm total length, indicating the similarity of the size of these fish available to the troll fishery.

Table X shows the summary of the troll catch per month of the different species of tuna by the research vessel S. F. Baird from September 1947 through November 1949.

The difference in the availability of the different species of tuna is apparent. During December 1947 the catches of the skipjack, yellowfin and yaito tuna were more or less of the same quantity, yet during the months of January, May and November the number of yaito tuna taken was much more than in the other months indicating a distinct schooling characteristic of these fishes.

The operations during the year 1948 may be used to assess the differences in the availability of the different species of tuna during the different months.

More skipjacks were taken during the months of March to July which is the tuna season in the Philippines. In fact, the catch of the yellowfins and the yaito tuna during this period is also higher than during other months of the year.

Figures 17 to 21 show the size distributions of the skipjack, yaito tuna, dogtooth tuna and scaly tuna caught by the research vessels of the Philippine Fishery Program arranged in localities (fishing grounds) of increasing latitude. There appears to be a widespread distribution of skipjacks and yaito tunas of similar mean lengths (total length) all over Philippine waters. Although larger yaito tuna appears to be more concentrated in the southern part of the Philippines, while the larger skipjack are found north of Mindanao Island the dogtooth and scaly tunas are confined to a few fishing grounds in the southwestern part of the Philippines.

Table IX

Summary of tunas caught by the exploratory fishing vessels S. F. Baird, T.N. Gill and D.S. Jordan by trolling from 1947 through 1949 fishing operations in the Philippine waters.

Research Vessel	Yellowfin	Skipjack	Yaito tuna	Dogtooth tuna	Scaly tuna	Total
S. F. Baird	254	362	371	2	33	1022
T.N. Gill	28	10	76	70	2	186
D. S Jordan	0	3	8	11	0	22
Total	282	375	455	83	35	1230

Table X

Summary of the number of different species of tuna caught per month by the research vessel S. F. Baird from September 1947 through November 1949

Month	Skipjack	Yellowfin	Yaito tuna	Scaly tuna
1947-				
Sept.	-	-	-	-
Oct.	-	-	-	-
Nov.	-	-	-	-
Dec.	25	34	25	-
1948-				
Jan.	1	5	41	-
Feb.	7	-	1	-
March	20	12	14	-
April	47	24	39	-
May	58	42	89	3
June	90	48	23	-
July	37	26	18	6
Aug.	13	23	1	-
Sept.	4	12	-	-
Oct.	-	-	14	-
Nov.	22	3	87	24
1949-				
Jan.	3	-	-	-
Feb.	9	3	-	-
May	1	-	3	-
June	5	11	-	-
Aug.	3	-	4	-
Sept.	4	3	-	-
Oct.	5	8	-	-
Nov.	8	-	12	-
Total	362	254	371	33

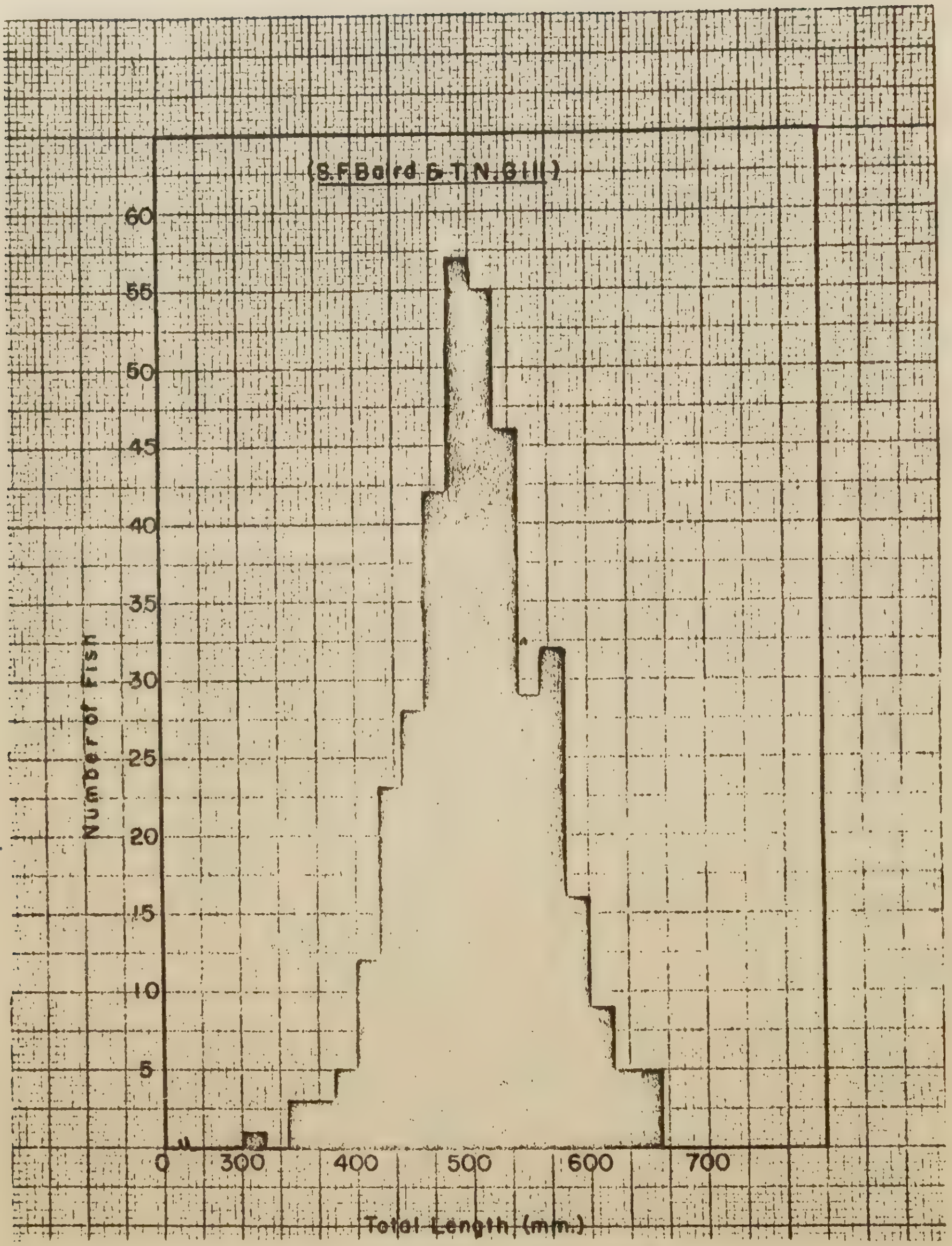

Figure 15. Length frequency distribution of Katsuwonus pelamis taken by trolling in Philippine waters 1947-1949 by Baird and Gill.

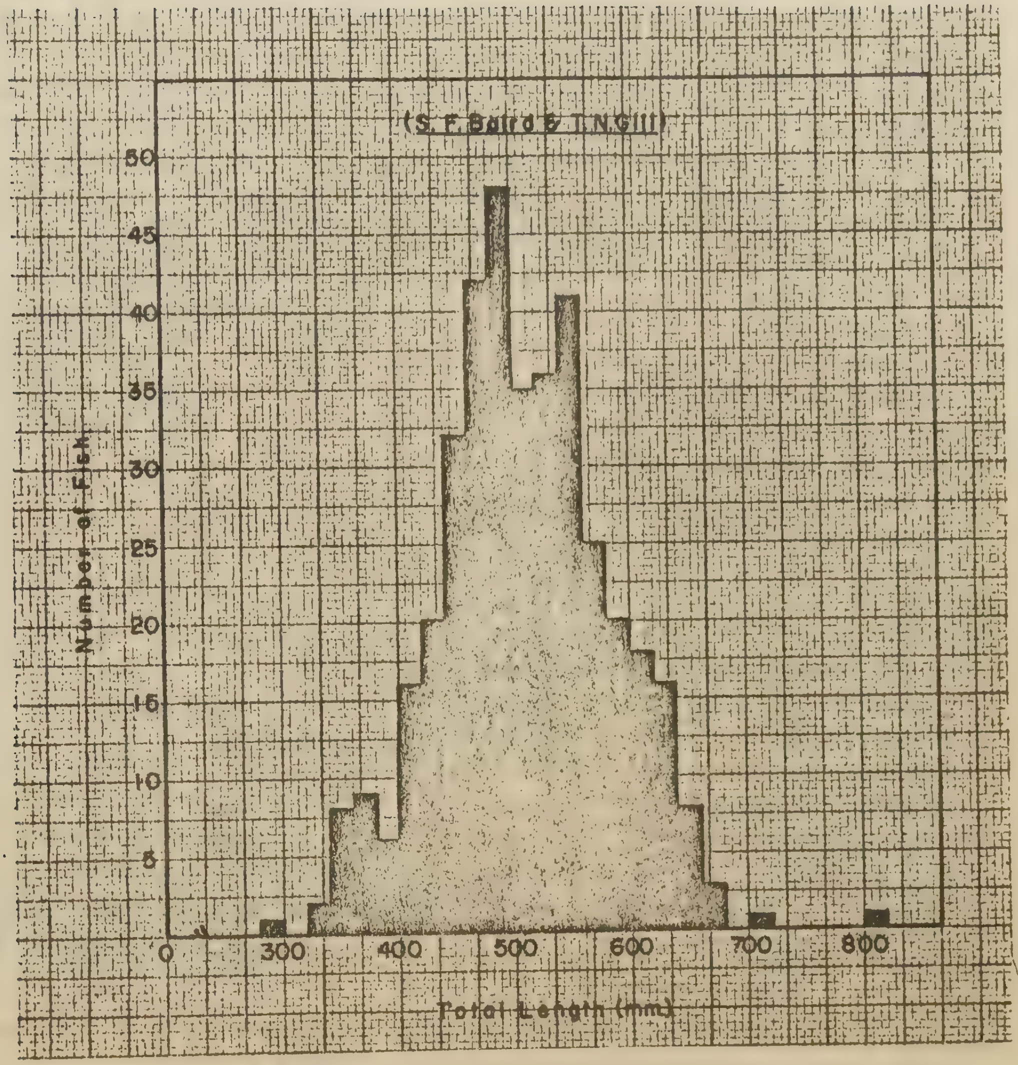

Figure 16. Length frequency distribution of Euthynnus yaito taken by trolling in Philippine waters 1947 - 1949.

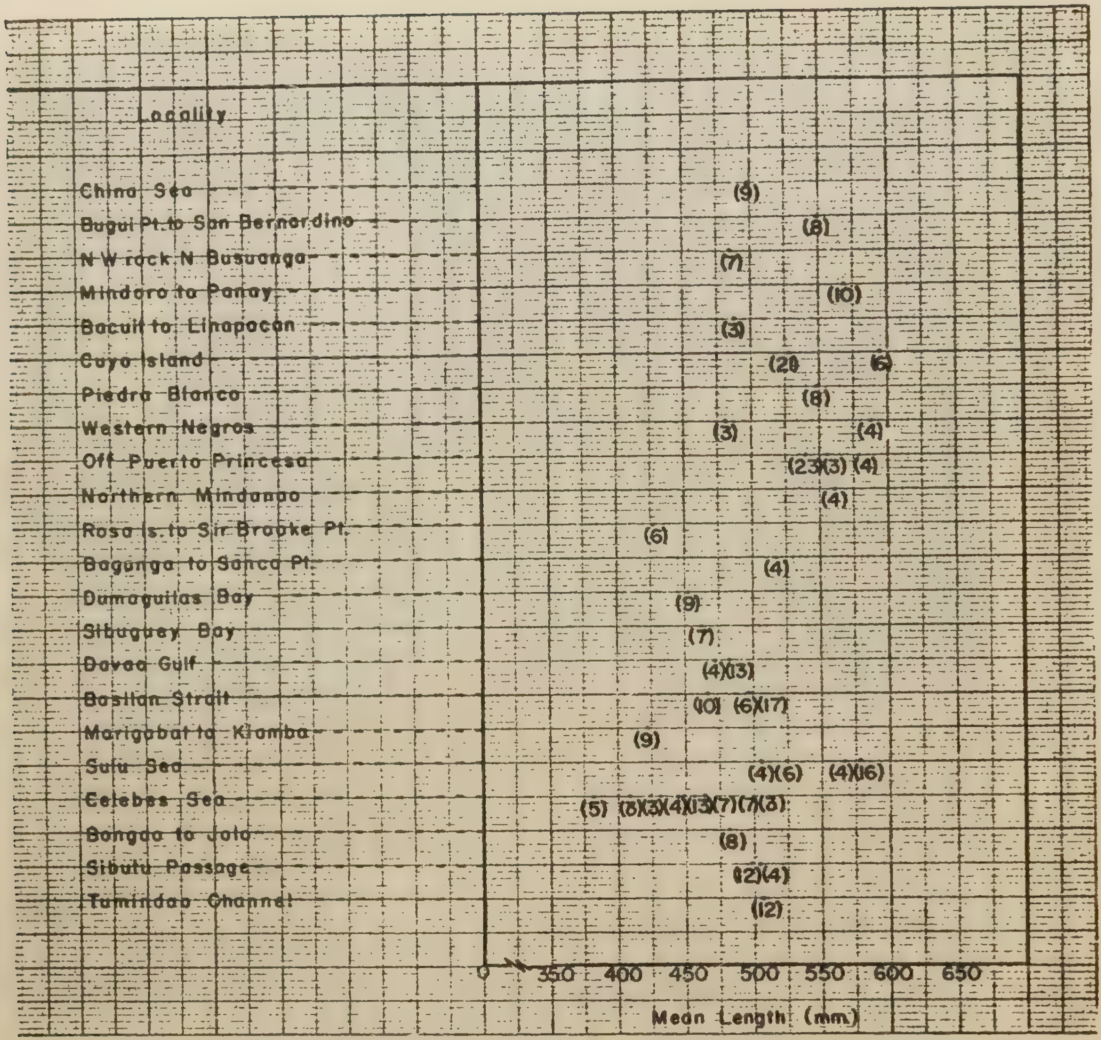

Figure 17. Size distribution of Katsuwonus pelamis caught by trolling (Baird) 1947 - 1949 in Philippine fishing grounds.

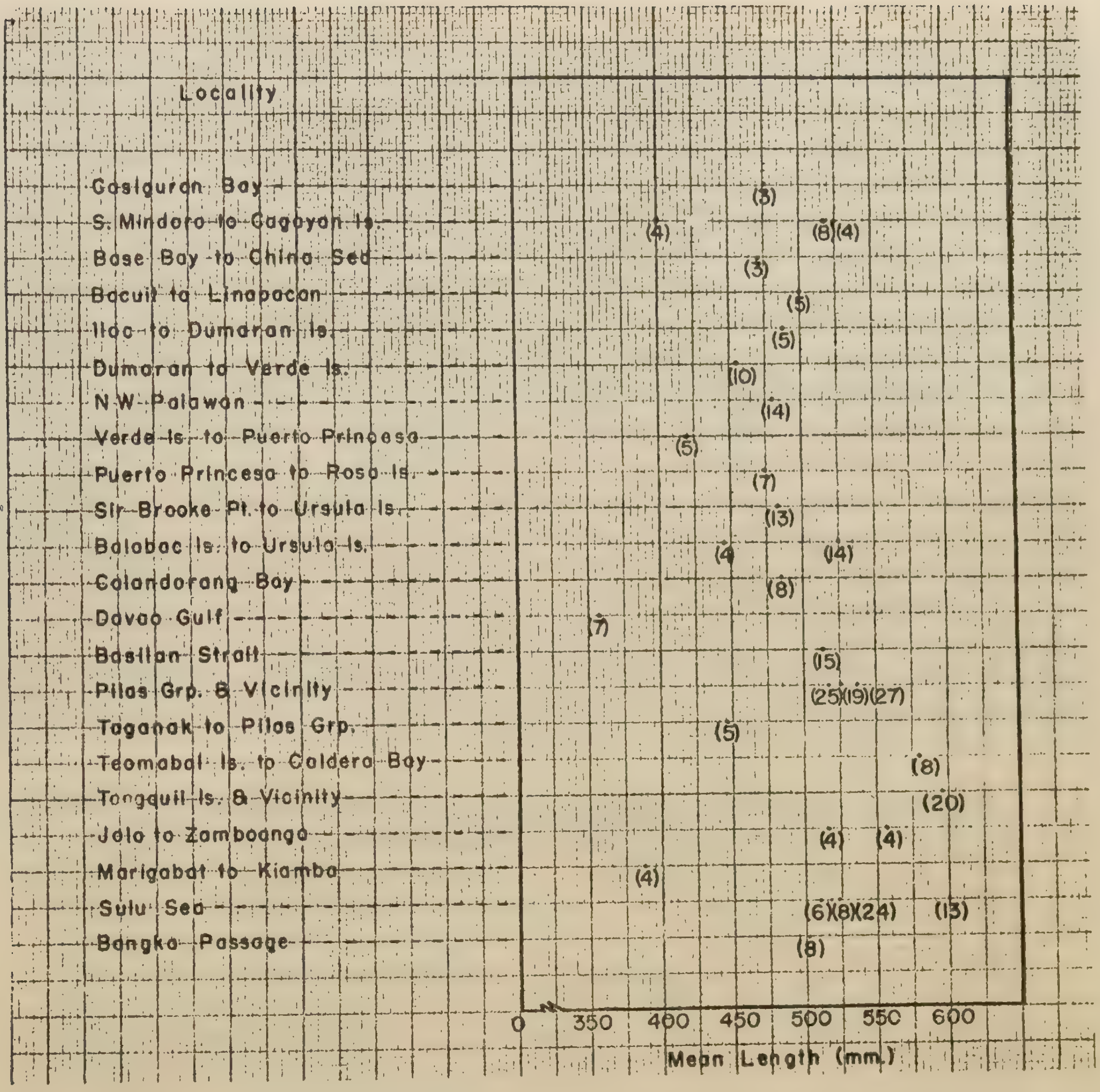

Figure 18. Size distribution of Euthynnus yaito caught by trolling (Baird) 1947-1949 in Philippine fishing grounds.

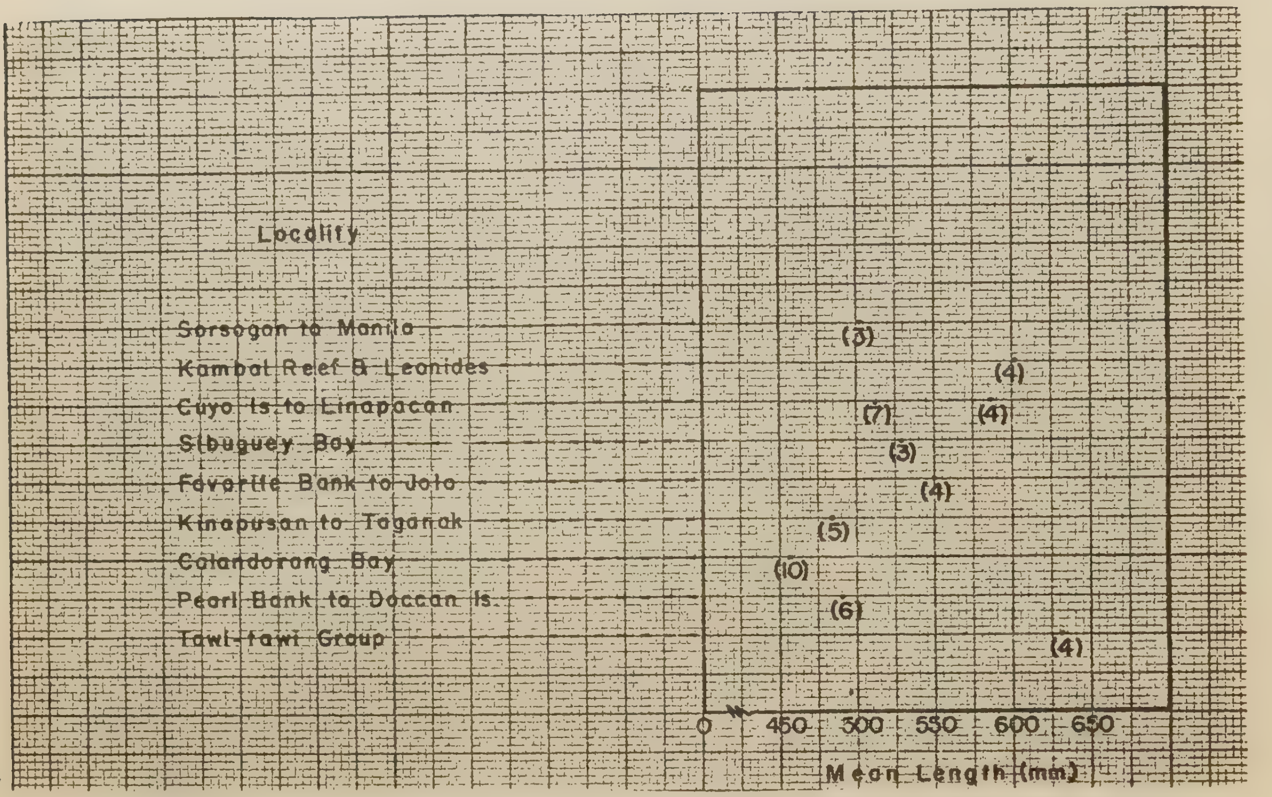

Figure 19. Size distribution of Euthynnus yaito caught by trolling (Gill) 1948 - 1949 in Philippine fishing grounds.

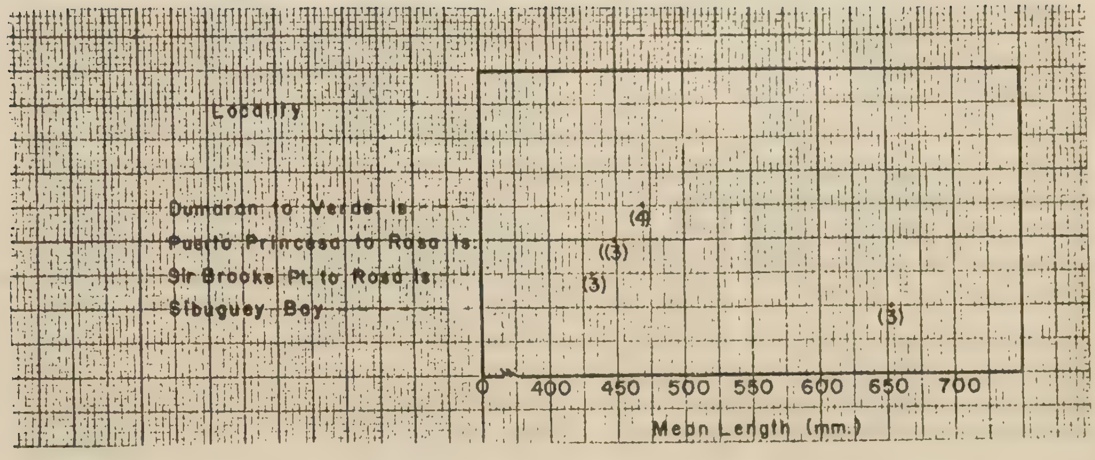

Figure 20. Size distribution of Kishinoella tonggol caught by trolling (Baird) 1947 - 1949 in Philippine fishing grounds.

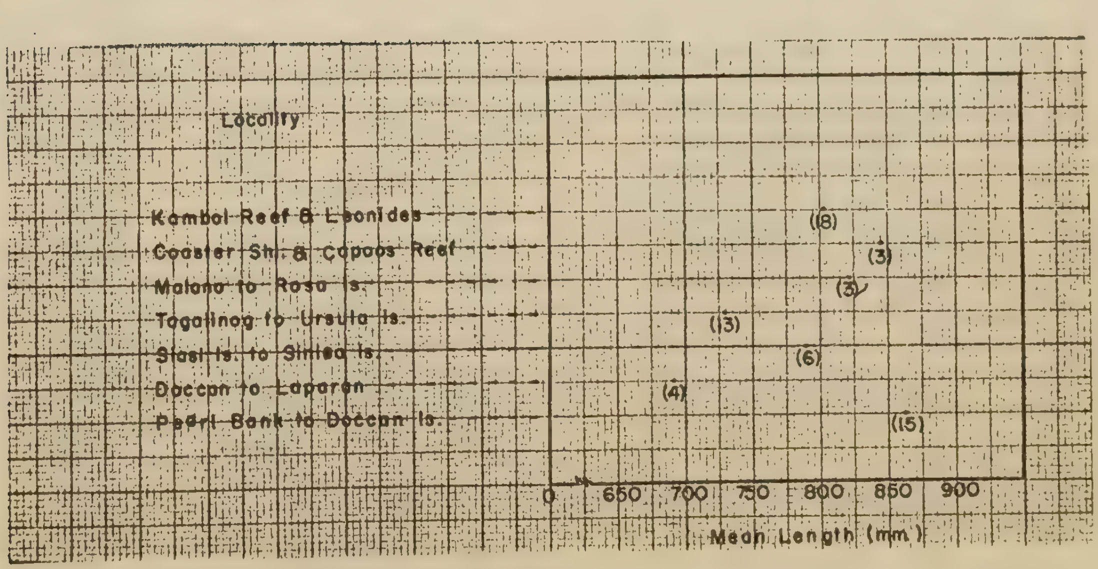

Figure 21. Size distribution of Gymnosarda nuda caught by trolling (Gill) 1948 - 1949 in Philippine fishing grounds.

3.3 Length-weight relationship

Length-weight relationships were calculated for each of the five most abundant species of tunas taken by trolling according to the formula $W = kL^x$ or in logarithmic form - log W = log k 1 x log L. Weight (W) were in pounds and length (L) were in mm.

The constant log k and x were determined by the method of least squares and are given in Table XI together with other pertinent data. When many specimens were available the constants were determined by sexes.

The close relationships between the weights of a given size of the males and females of each species could be seen from the very slight difference between the k values and the regression coefficients.

The length-weight relationships for each species were plotted in Figures 22 to 33.

3.4 Spawning activities of Philippine tunas

Using the procedure of Kikawa (MS) wherein the gonad index represents the ratio of the weight of a pair of ovaries in grams to the cube of the total length in mm (gonad index = $Wo/L^3 \times 10^4$), the data on the weights of the ovaries of the yellowfin, skipjack, yaito tuna, dogtooth tuna, and scaly tuna which were caught by the S. F. Baird from September 1947 through November 1949 and T. N. Gill from February 1948 through October 1949 were analysed to determine their spawning activities. Tables XII, XIV, XVI and XVIII give the number, ranges in total length, ovarian weights, gonad index and percentage for the different species of tuna studied. Examination of the data show that even after a fish has reached a minimum length representing length at first maturity with a gonad index of 3, the gonads may again decrease in weight considerably during the non-spawning season. Tables XIII, XV, XVII and XIX give the monthly mean gonad indices which may help determine the height of spawning activities of the different species.

3.4.1 Yellowfin

Table XII shows the distribution of lengths (total length) of yellowfin tuna to gonad index. Only a few fish (eight) or 11.40 percent have a gonad index of 3 and greater.

The majority of the catch by trolling (60.27 percent) from 426 mm to 828 mm total length have a gonad index of less than 1 and 28.77 percent with total length range of 495 mm to 769 mm have a gonad index from 1 to 3. Inasmuch as this is a fish that matures at a much larger size as can be seen from Figure 1 it is not surprising that only immature forms are available to trolling. The older age groups form the deep-swimming tuna which are fished only by longline.

Whereas both the skipjack and yaito tuna are already mature from 400 mm total length, the yellowfin starts to mature only from 550 mm to 670 mm total length and only a few are mature even at that size range.

Table XIII shows that the yellowfin with a gonad index of 2 or greater is found during the months of March, April, May, June, July, August and December but few fish with high degree of maturity were taken during the early part of the year. These months are the tuna season in the Philippines and as has been reported in other areas, the spawning season coincides with the height of the fishing season (June 1950). However, the prolonged spawning condition of the fish is indicated and confirms findings of Kikawa (MS) that yellowfins breed from Luzon Islands to southern Japan during April to June.

Figure 34 shows the distribution of gonad indices to total lengths of the yellowfin. It will be seen that a majority of troll-caught yellowfins are immature.

3.4.2 Skipjack

Figure 35 shows that a great majority of the skipjacks have a gonad index from 3 to 8 starting from a total length of 420 mm indicating that this fish is indeed breeding in Philippine waters as has been found by Wade (1950). It may be noted that the condition of the gonad does not depend upon the length of the fish for the gonad index of 3 and greater is scattered among all the ranges as soon as the fish starts to mature.

Table XIV gives the summary of the distribution of gonad indices to range in total lengths, gonad weights and percentage of each range for the skipjack. It may be seen that the fish starts to mature at a total length of 419 mm with a gonad weight of 22.4 g and with a gonad of 3.0 and is ready to spawn.

Table XI

Number of fish, size range, and constants in the length-weight relations (log W = log k + x log L) for five species of troll-caught tuna by the S. F. Baird and T.N. Gill compared with the deep-swimming species (yellowfin and bigeye) caught by the Malasugui

Species	Number of Fish	Size Range (mm)	Log K	k	x	Caught by Research Vessel
Yaito tuna Male Female	203 165	344-810 331-652	-4.13317 -4.33240	0.00001358 0.00002150	2.83768 2.94854	Baird & Gill
Skipjack Male Female	189 151	345-655 340-627	-4.51415 -4.29566	0.00003267 0.00001976	3.09569 2.96482	Baird & Gill
Dogtooth tuna	70	510-965	-4.86483	0.00007325	3.20623	Gill
Scaly tuna	30	405-660	-3.28208	0.0001915	2.30847	Baird & Gill
Yellowfin Male Female	106 78	320-828 472-805	-3.90564 -4.01191	0.0008047 0.0001028	2.73643 2.78797	Baird & Gill
Yellowfin Male Female	99 43	827-1840 1096-1530	-4.37146 -4.63570	0.0002352 0.00004322	2.84682 2.87651	Malasugui
Bigeye Male Female	27 28	1120-1859 1050-1704	-4.67998 -4.23582	0.00004786 0.00001721	2.94430 2.74669	Malasugui

Table XII

Number and percentage of yellowfin tuna taken by trolling in relation to the ranges of total lengths, of gonad weights and gonad indices.

No. of fish	Range of total lengths (mm)	Range of gonad weights (g)	Gonad index	Percent of total
54	426 - 828	1.0 - 52.3	0.1 - 0.9	60.27
15	495 - 745	17.0 - 77.2	1.1 - 1.9	16.44
9	532 - 769	39.3 -103.4	2.2 - 2.9	12.33
5	556 - 614	58.5 - 76.2	3.2 - 3.8	6.99
3	610 - 673	99.2 - 131.39	4.3 - 4.8	4.41

Table XIII

Distribution of yellowfin tuna taken by trolling of varying gonad indices to months of capture together with other pertinent data.

Months of Capture	Length range (mm)	Mean length (mm)	No.	Gonad Index range	Gonad Index range mean
1947-49					
March	587 - 604	585	2	3.8 - 4.8	4.3
April	556 - 614	535	2	3.2 - 3.6	3.4
April	596 - 665	630	4	0.6 - 0.8	0.7
May	472 - 769	565	12	0.2 - 2.3	1.2
June	613 - 805	673	21	0.1 - 2.5	1.3
July	495 - 758	564	5	0.2 - 2.8	1.5
August	487 - 570	530	7	0.3 - 2.4	1.4
September	543	543	1	1.1	1.1
October	690 - 693	691	2	0.3 - 0.8	0.5
November	580 - 620	570	3	0.6 - 0.8	0.7
December	568 - 673	620	4	3.2 - 4.3	3.8
December	512 - 602	559	10	0.3 - 2.8	1.6

Table XIV

Number and percentage of skipjack taken by trolling in relation to the ranges of total lengths, of gonad weights and gonad indices.

No. of fish	Range of total length (mm)	Range of ovarian weights (g)	Gonad Index	Percent of total
3	553 - 560	3.25 - 8.2	.2 - .5	1.97
11	375 - 605	7.0 - 44.1	1.3 - 1.9	7.24
21	396 - 618	14.0 - 57.2	2.1 - 2.9	13.13
44	419 - 615	22.4 - 83.9	3.0 - 3.9	28.95
29	425 - 607	31.2 -104.6	4.0 - 4.9	19.08
17	445 - 583	51.6 -103.8	5.0 - 5.9	11.18
9	445 - 627	53.5 -150.0	6.0 - 6.8	5.98
8	455 - 582	66.5 -142.0	7.8 - 7.9	5.26
6	340 - 520	33.5 -120.0	8.1 - 8.8	3.95
2	500 - 597	119.9 -208.5	9.6 - 9.8	1.32
2	405 - 491	67.7 -126.1	10.2 -10.7	1.32
1	505	168.2	13.1	.66

Table XV

Distribution of skipjack of different gonad indices to months of capture together with other pertinent data.

Month of Capture	Length range (mm)	Mean length (mm)	No.	Gonad Index range	Gonad Index range mean
1947 - 1949					
January	515 -	515	1	8.8 -	8.8
February	463 - 545	503	6	5.1 - 8.3	6.7
	560	560	1	0.2 -	0.2
March	425 - 582	492	7	3.0 - 7.2	5.1
April	426 - 607	510	17	3.3 - 8.3	5.8
	422	422	1	2.1 -	2.1
May	419 - 568	482	16	3.0 - 7.5	5.3
	438 - 541	485	8	1.7 - 2.9	2.3
June	458 - 615	533	38	3.0 - 9.8	6.4
	538 - 618	563	12	0.3 - 2.9	1.6
July	340 - 627	497	11	3.0 -10.2	6.6
	508 -	508	1	2.9 -	2.9
August	431 - 580	483	3	3.1 - 4.5	3.8
	420 -	420	1	1.9 -	1.9
September	460 - 466	465	4	4.4 - 8.1	6.3
November	495 - 568	536	5	3.0 - 3.9	3.5
	430 - 542	500	6	1.5 - 2.9	2.3
December	465 - 505	490	8	3.4 -13.0	8.3

Table XVI

Number and percentages of yaito tuna taken by trolling in relation to ranges of total lengths, of gonad weights and gonad indices.

No. of fish	Range of total lengths (mm)	Range of ovarian weights (g)	Gonad Index	Percent of total
19	334 - 578	1.2 - 15.5	0.13 - 0.98	13.28
49	331 - 652	4.2 - 51.5	1.0 - 1.9	34.06
29	406 - 632	16.0 - 66.4	2.0 - 2.9	20.20
15	384 - 644	18.0 - 96.5	3.0 - 3.9	10.48
10	410 - 593	30.0 - 94.0	4.0 - 4.9	6.99
12	428 - 621	40.0 -123.5	5.0 - 5.9	8.39
4	395 - 604	42.4 -143.4	6.1 - 6.8	2.78
3	464 - 585	74.0 -161.2	7.0 - 7.4	2.08
1	505	119.0	9.2	.69
1	553	185.7	10.9	.69
1	508	220.0	16.8	.69

Table XVII

Distribution of yaito tuna of different gonad indices to months of capture together with other pertinent data.

Month of capture	Length range (mm)	Mean length (mm)	No.	Gonad Index range	Gonad Index range mean
1947 - 1949					
March	455 - 571	503	9	3.5 - 16.8	10.1
April	395 - 593	520	9	3.2 - 6.9	5.0
	406 - 632	490	16	.5 - 2.9	1.7
May	428 - 644	540	10	3.0.- 7.5	5.2
	400 - 652	537	27	.5 - 2.9	1.7
June	401 - 491	450	2	3.8 - 5.9	4.9
	431 - 512	487	9	.1 - 2.8	1.4
July	450 - 582	546	6	4.5 - 6.1	5.3
	406 - 571	490	3	1.1 - 1.4	1.2
August	384	384	1	3.1	3.2
October	463	463	1	5.0	5.0
November	410 - 455	430	2	4.2 - 4.3	4.3
	385 - 535	463	28	0.5 - 2.6	1.6
December	462 - 621	542	7	3.9 - 7.0	5.5

Table XVIII

Number and percentage of dogtooth tuna and scaly tuna taken by trolling in relation to the ranges of total lengths, gonad weights and gonad indices.

No. of fish	Range of total lengths (mm)	Range of gonad weights (g)	Gonad Index	Percent of total
Dogtooth tuna				
5	510 - 942	18.5 - 130.0	1.1 - 2.0	83.33
1	760	88	2.0	16.67
Scaly tuna				
2	414 - 428	5 - 7	.7 - .9	12.50
11	405 - 488	8 - 17	1.1 - 1.5	68.75
1	648	76	2.8	6.25
2	430 - 660	31 - 100	3.5 - 3.9	12.50

Table XIX

Distribution of dogtooth tuna and scaly tuna of different gonad indices to months of capture together with other pertinent data.

Month of capture	Length range (mm)	Mean length (mm)	No.	Gonad Index range	Gonad Index range mean
Dogtooth tuna					
May	652 - 942	833	4	1.4 - 2.0	1.7
October	510	510	1	1.4	1.4
November	865	865	1	1.1	1.1
Scaly tuna					
May	660.2	660	1	3.5	3.5
	648	648	1	2.8	2.8
July	430	430	1	3.9	3.9
November	405 - 488	438	13	0.7 - 1.5	1.1

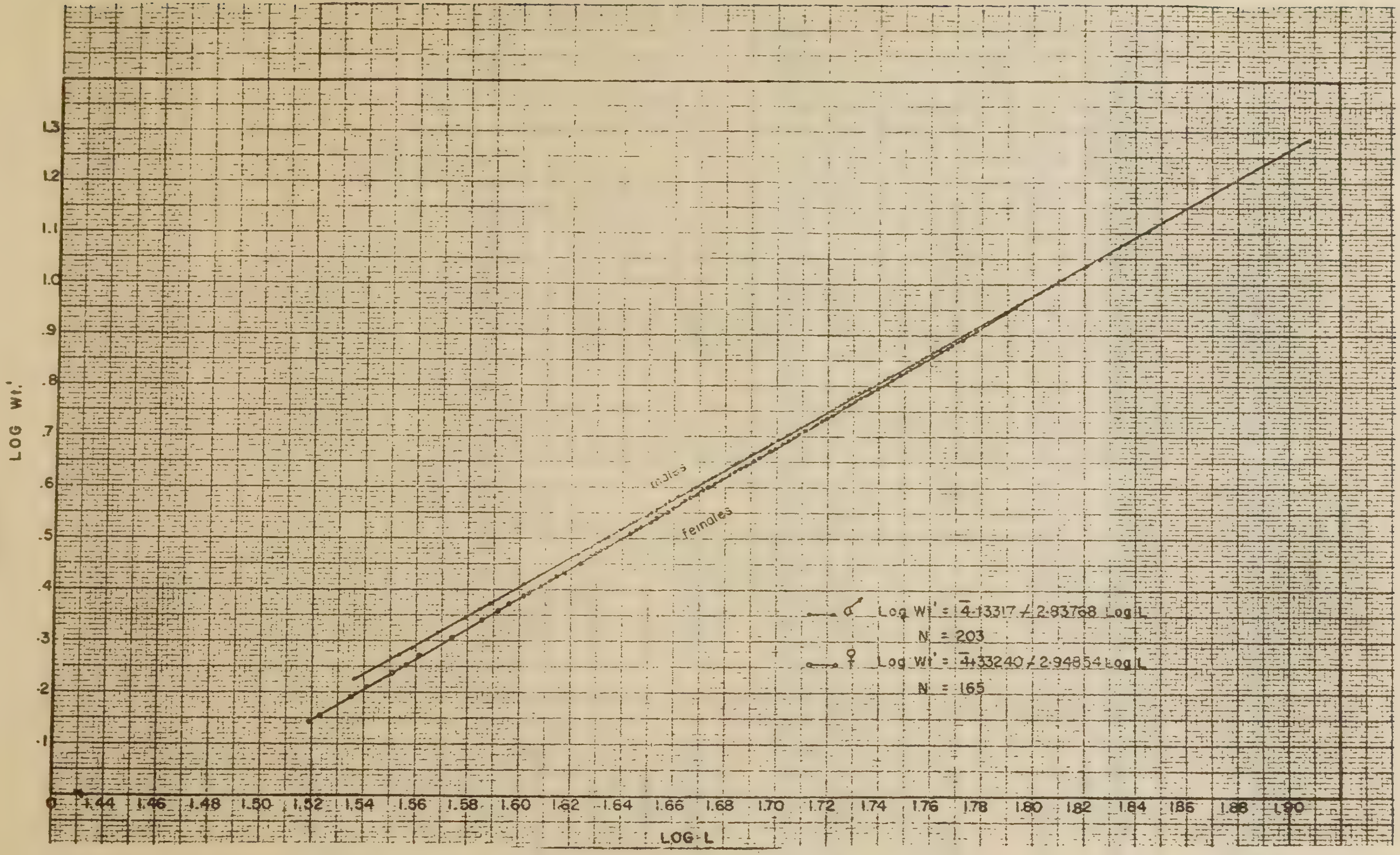

Figure 22. Regression of weight on length of Euthynnus yaito caught by trolling (S.F. Baird and T.N. Gill) in Philippine waters from 1947 through 1949.

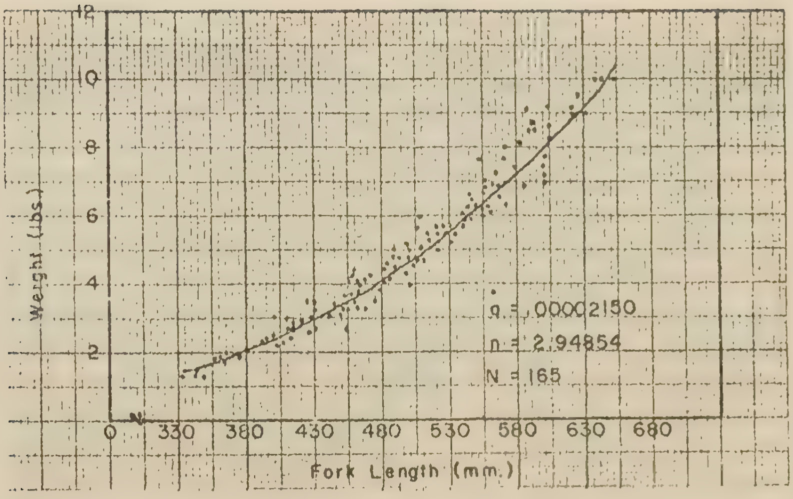

Figure 23. Length-weight relationship of *Euthynnus yaito* (females) caught by trolling (*Baird and Gill*) 1947 - 1949.

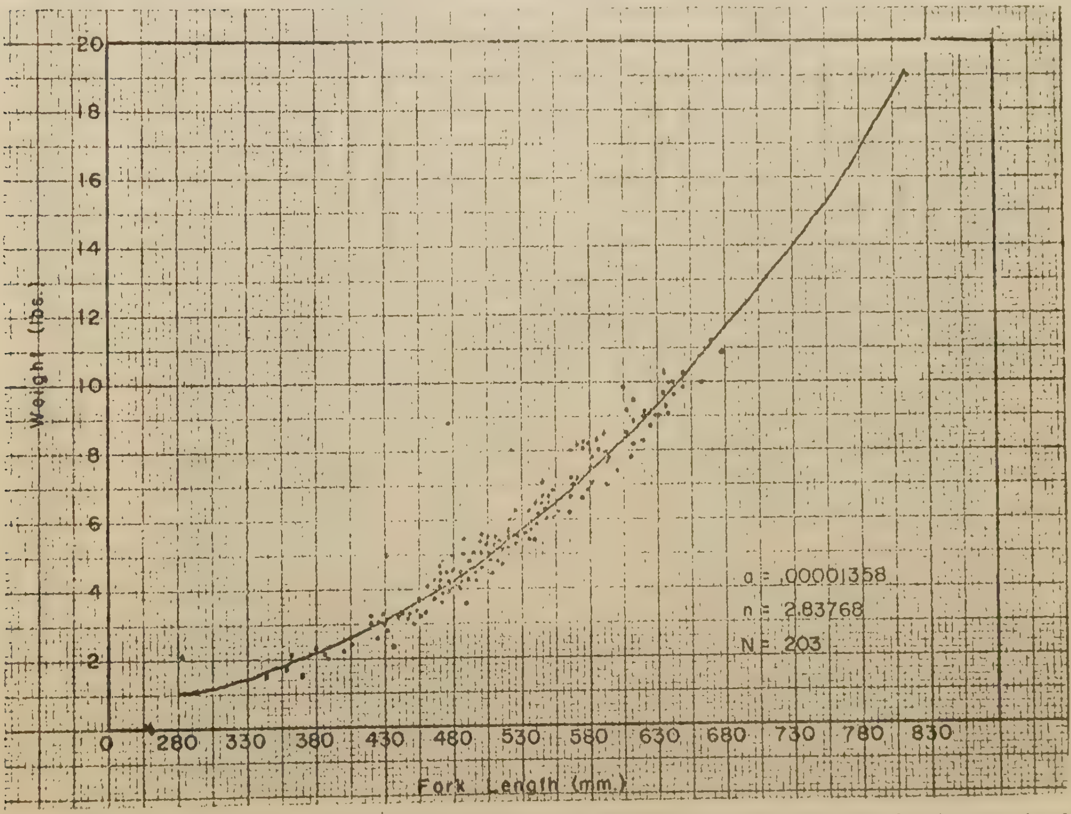

Figure 24. Length-weight relationship of *Euthynnus yaito* (males) caught bv trolling (*Baird and Gill*) 1947 - 1949.

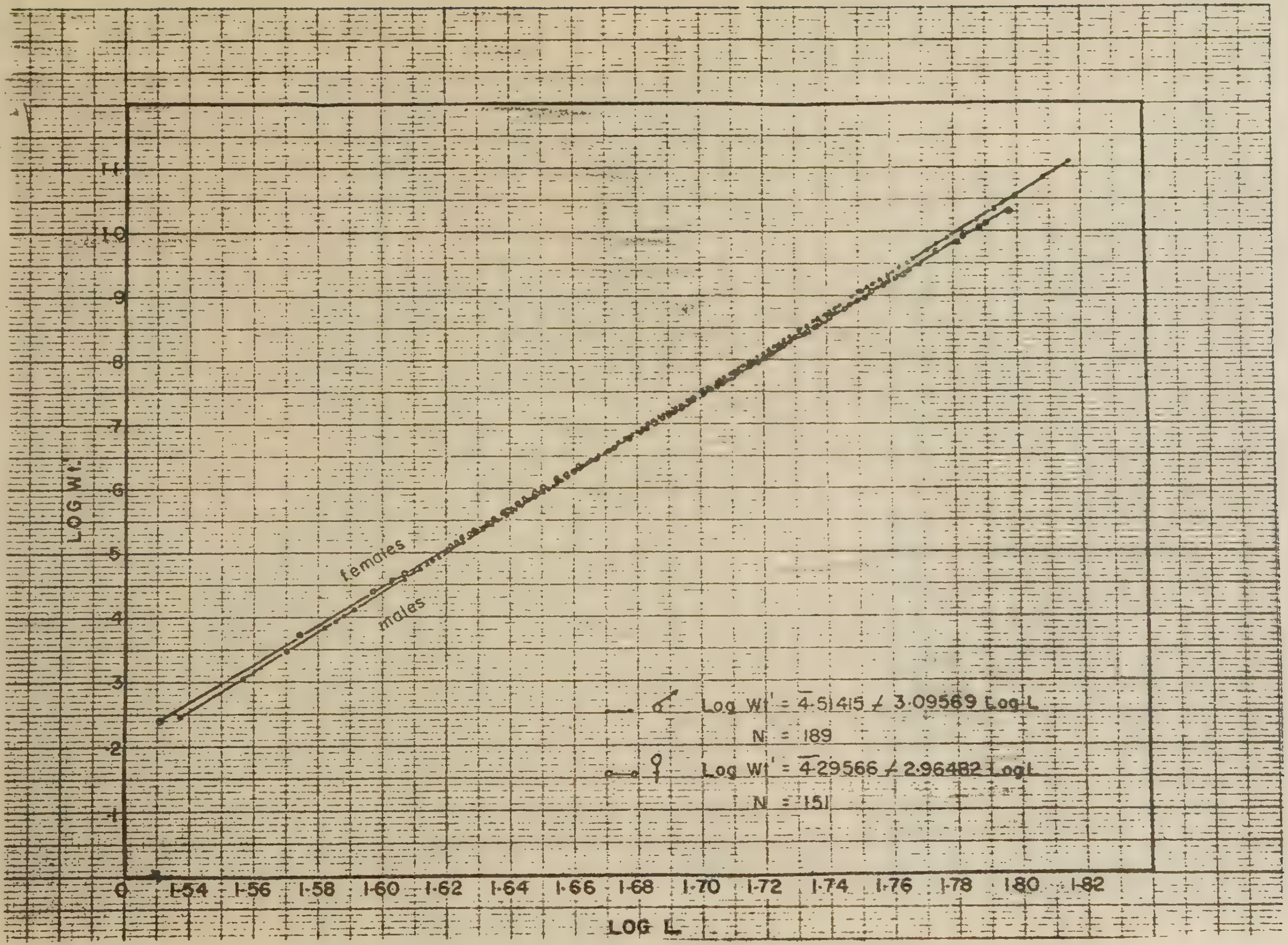

Figure 25. Regression of weight on length of Katsuwonus pelamis caught by trolling (S. F. Baird and T. N. Gill) in Philippine waters from 1947-1949.

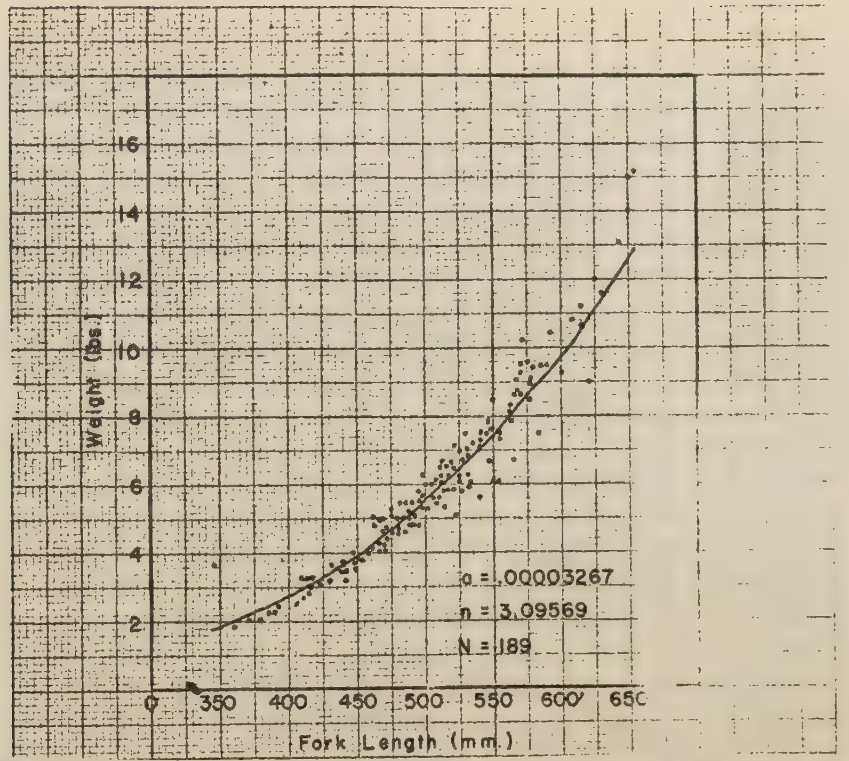

Figure 26. Length-weight relationship of Katsuwonus pelamis (males) caught by trolling (Baird and Gill) 1947 - 1949.

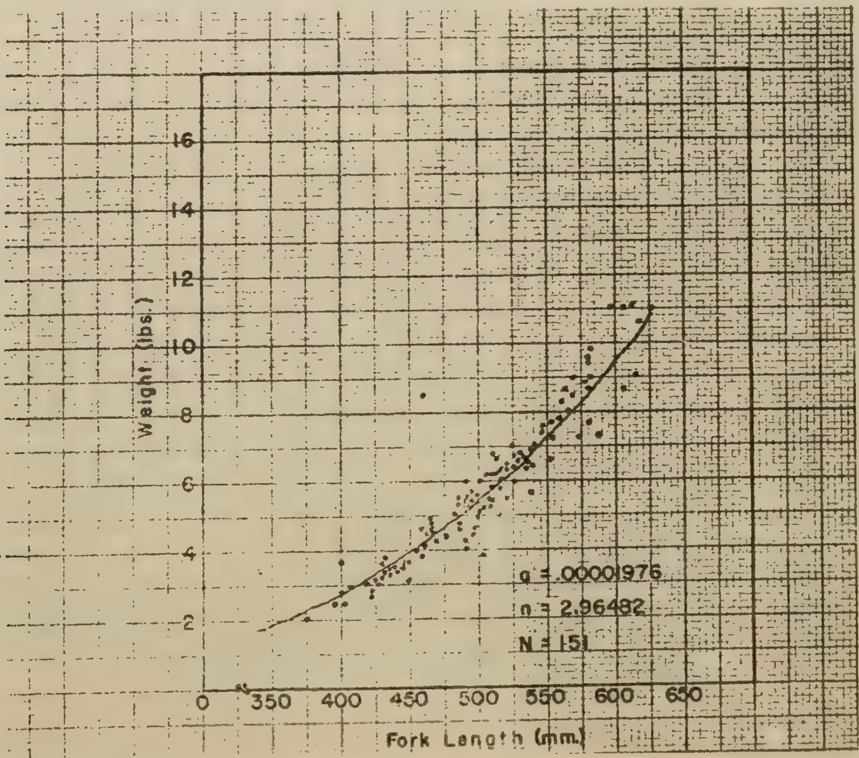

Figure 27. Length-weight relationship of Katsuwonus pelamis (females) caught by (Baird and Gill) 1947 - 1949.

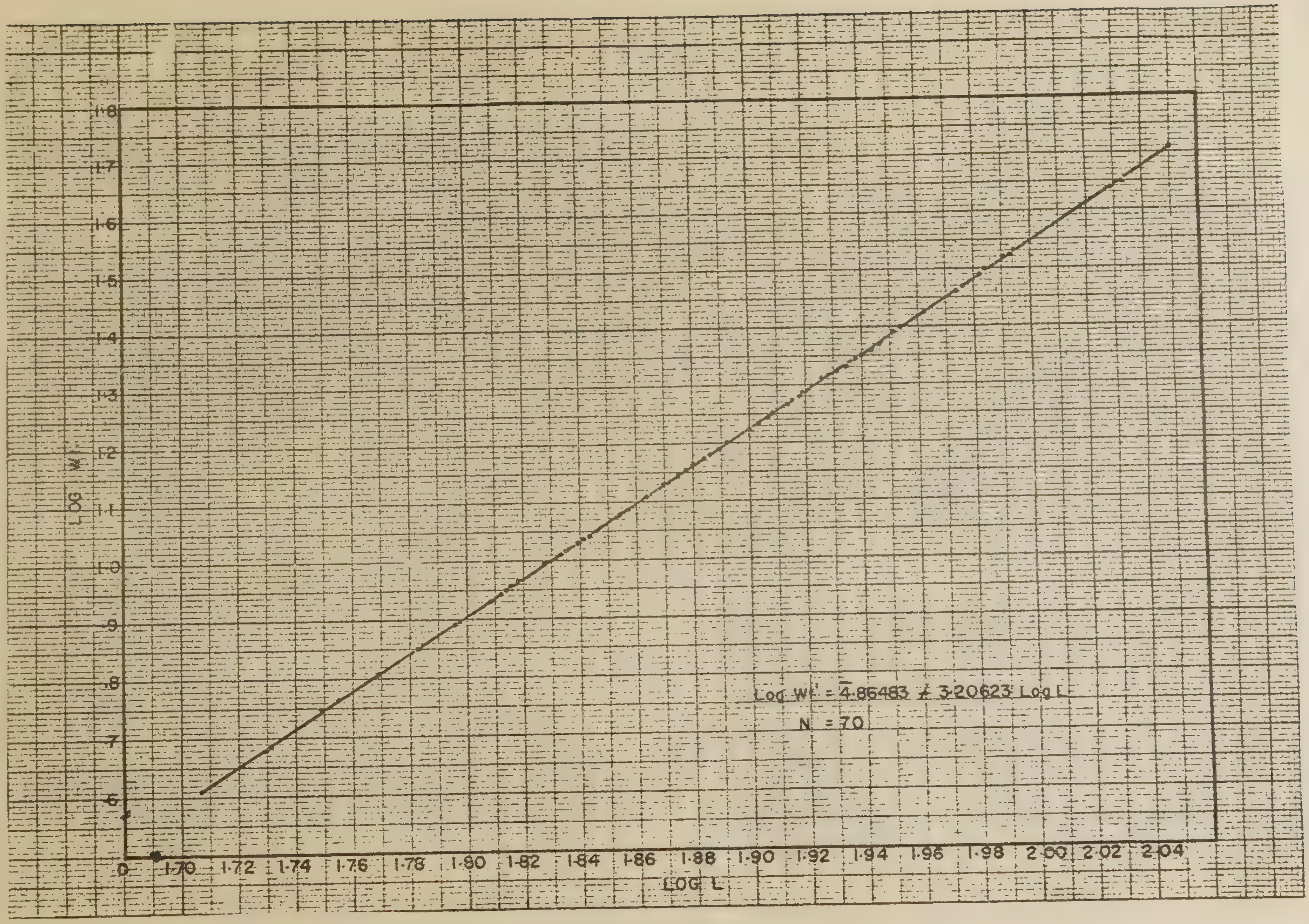

Figure 28. Regression of weight on length of Gymnosarda nuda caught by trolling (T.N. Gill) in Philippine waters in 1949.

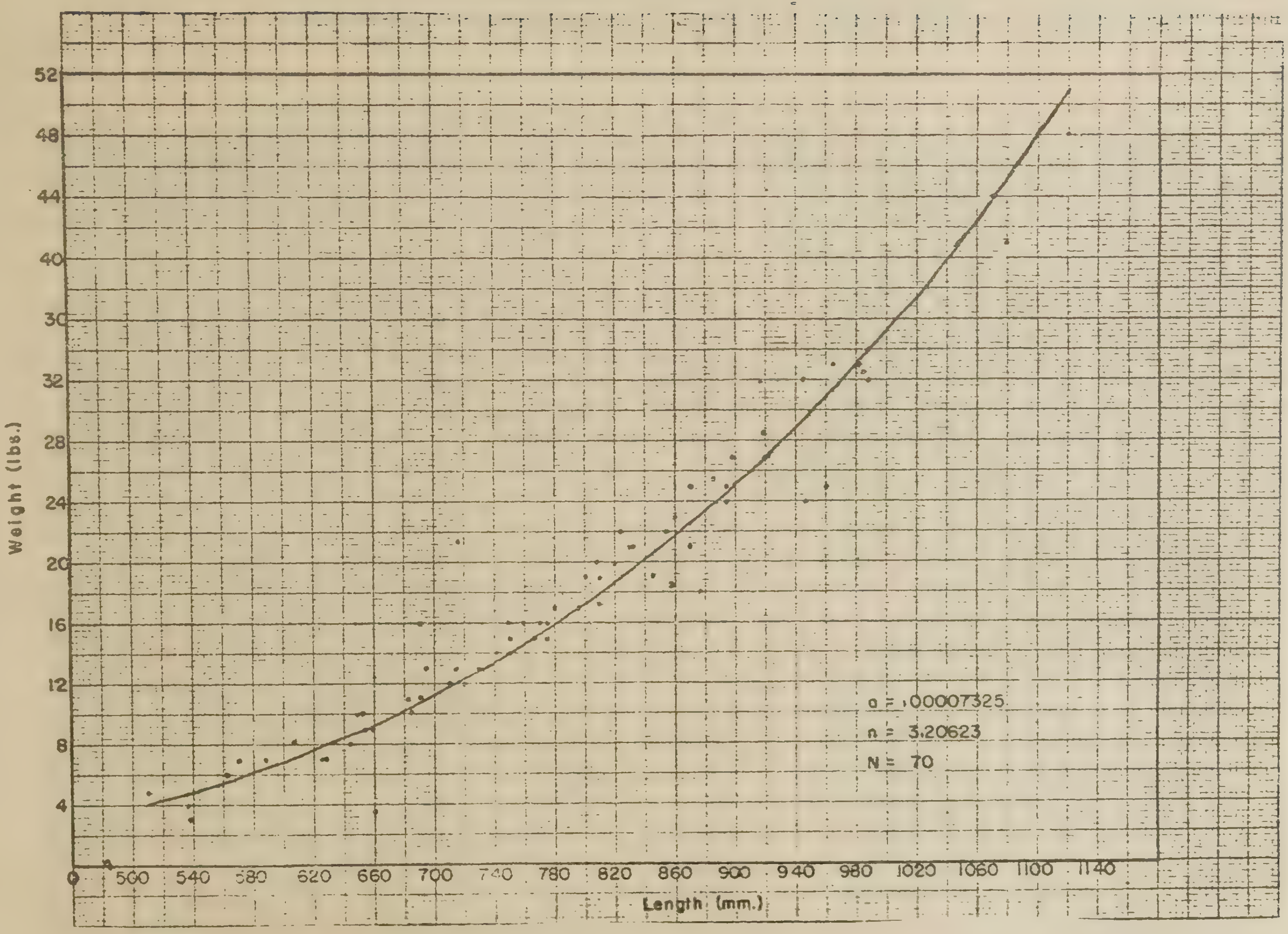

Figure 29. Length-weight relationship of *Gymnosarda nuda* caught by trolling (*Gill*) 1947 - 1949

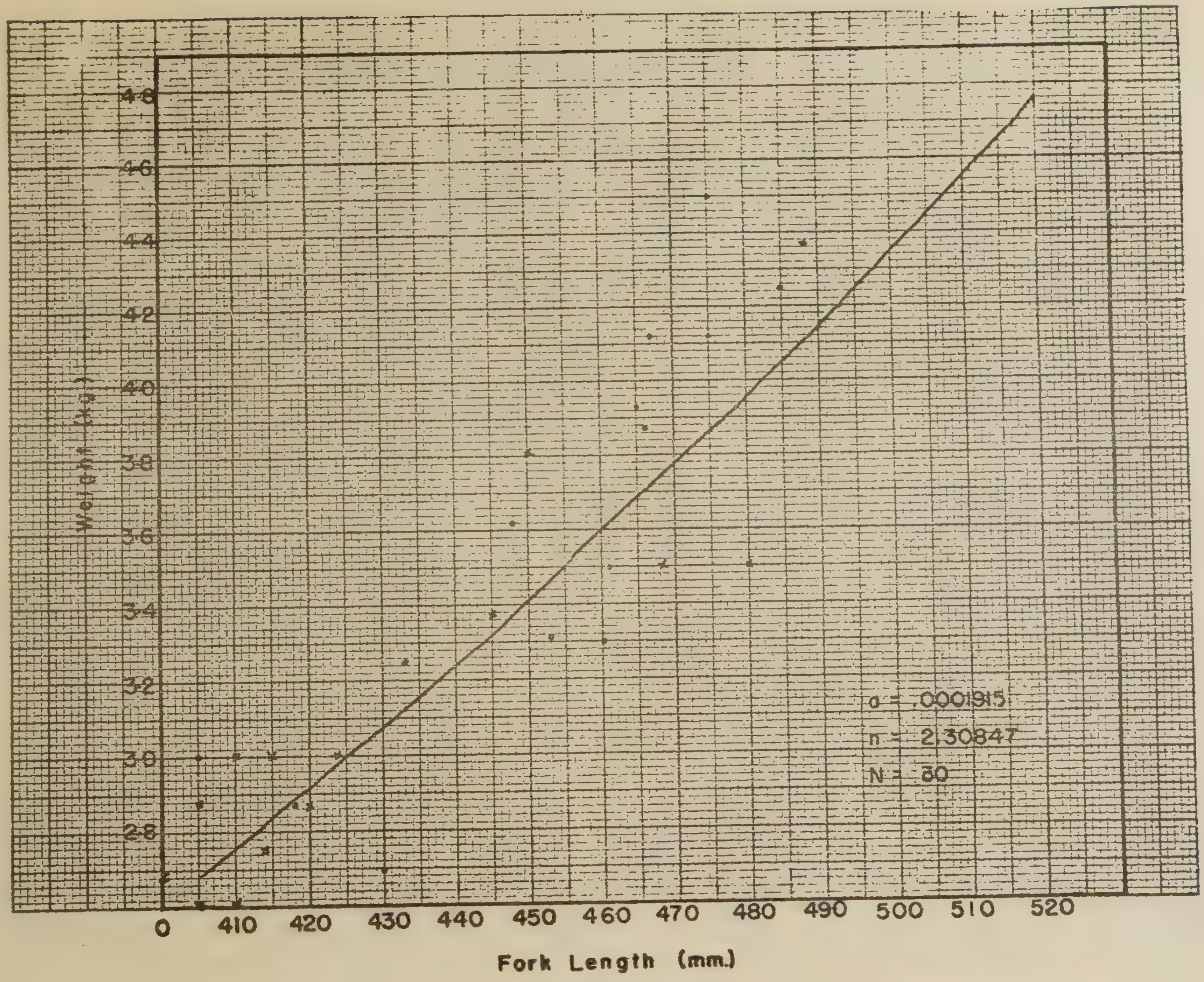

Figure 30. Length-weight relationship of *Kishinoella tonggol* caught by *Baird* and *Gill* in Philippine waters from 1947 - 1949

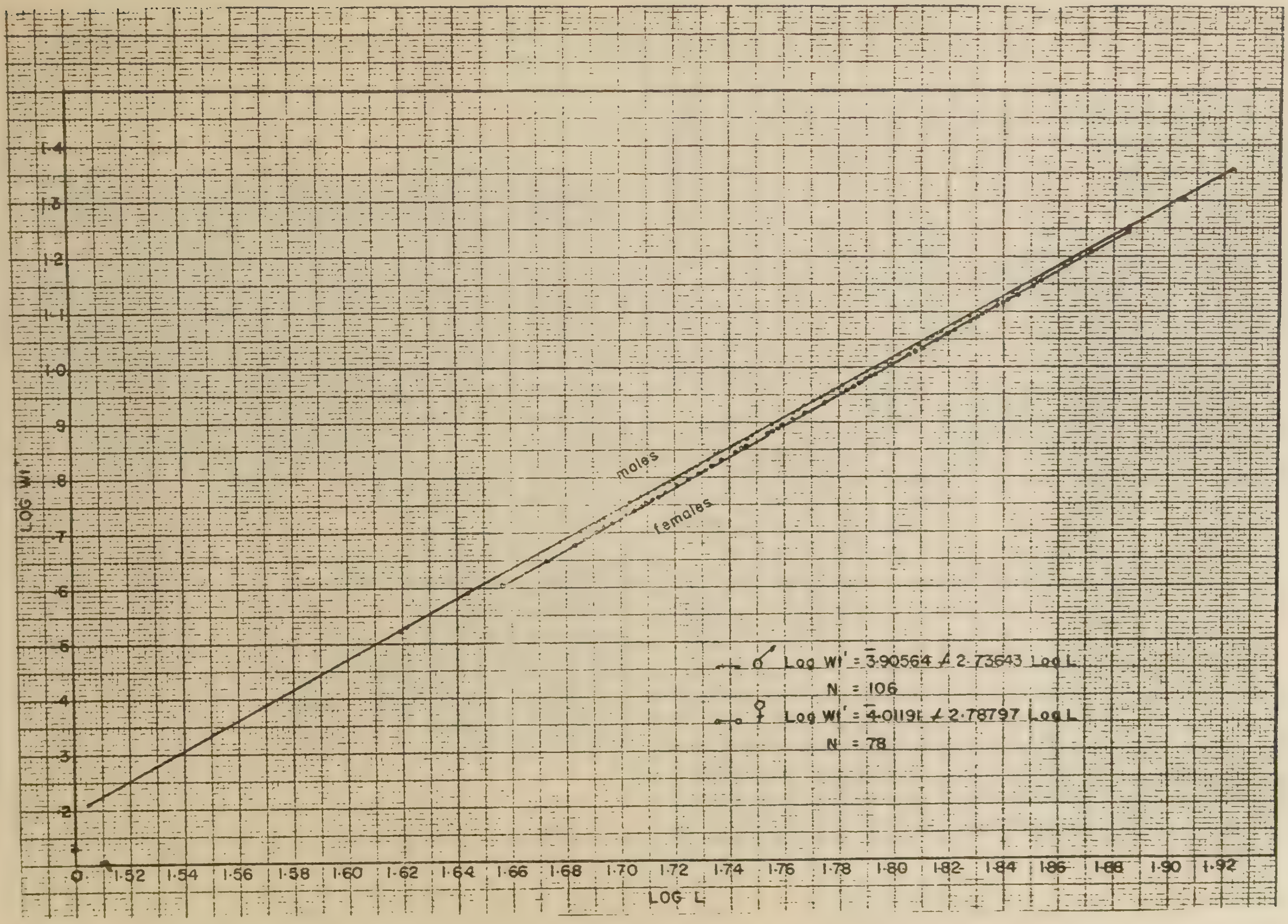

Figure 31. Regression of weight on length of Neothunnus macropterus caught by trolling (S. F. Baird and T.N. Gill) in Philippine waters from 1947 through 1949.

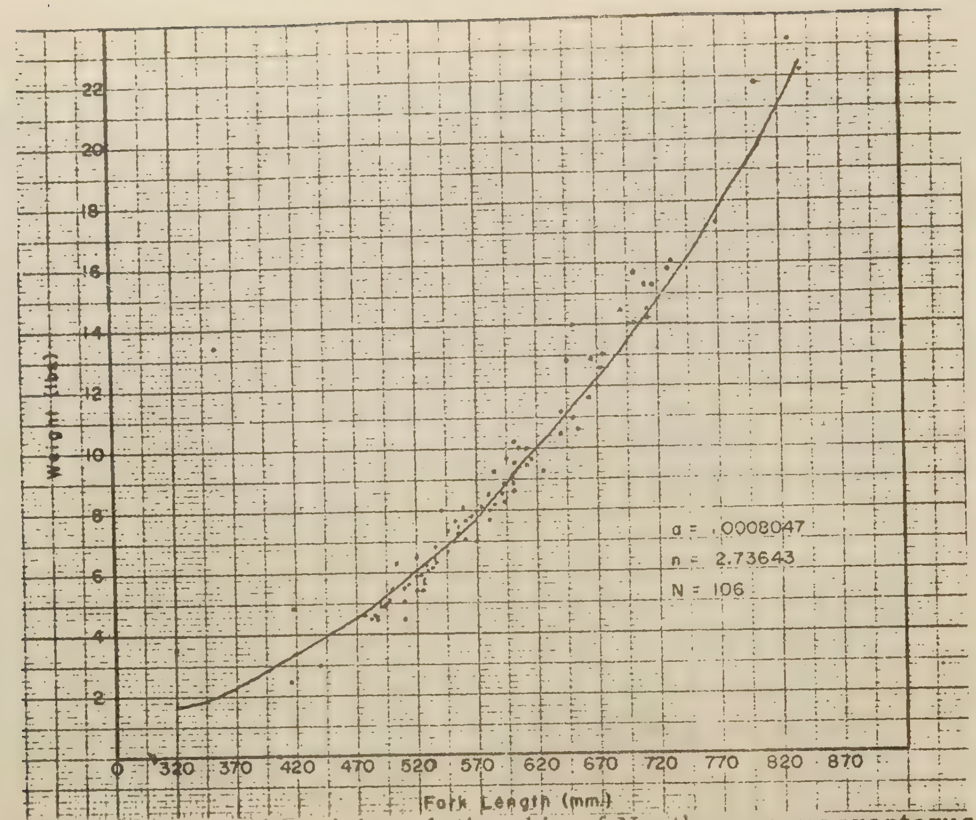

Figure 32. Length-weight relationship of Neothunnus macropterus (males) caught by trolling (Baird and Gill) 1947-1949

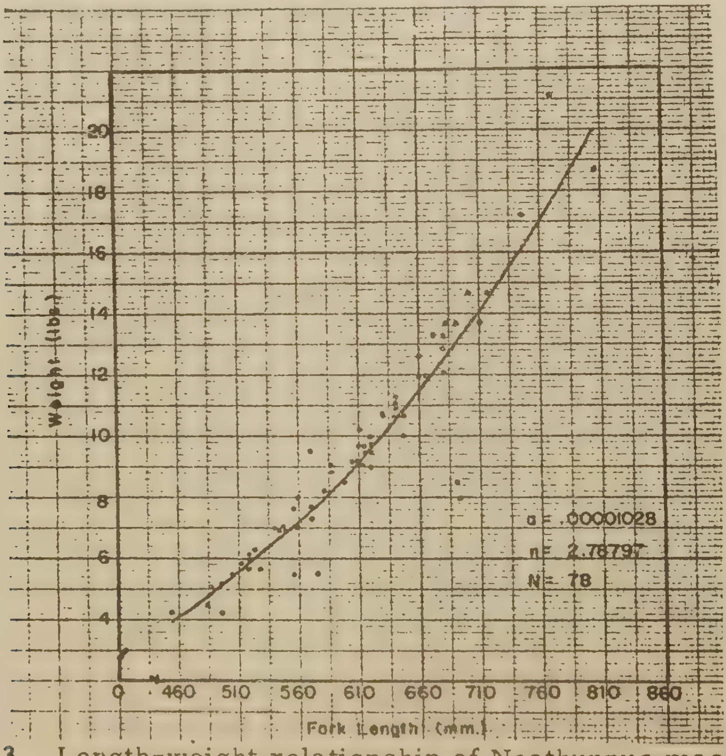

Figure 33. Length-weight relationship of Neothunnus macropterus (females) caught by trolling (Baird and Gill) 1947 - 1949.

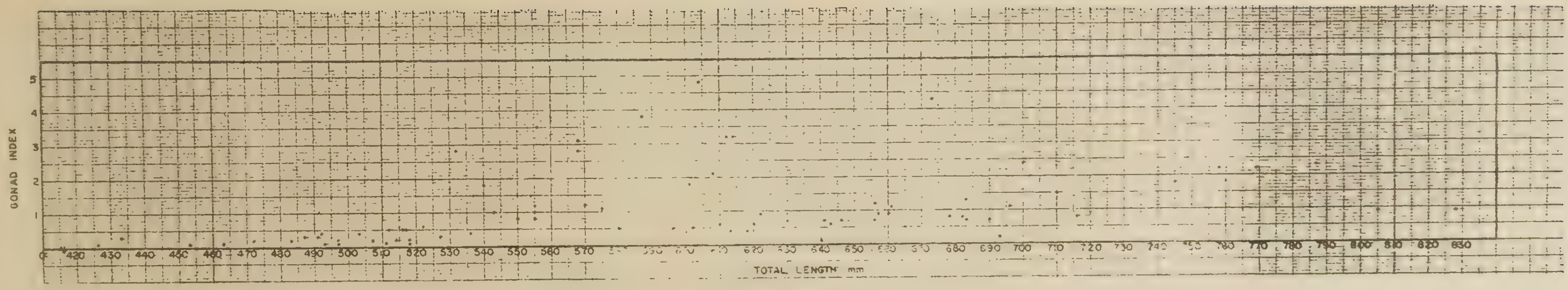

Figure 34. Gonad index of Neothunnus macropterus caught by trolling (Baird and Gill) 1947 - 1949 in Philippine waters.

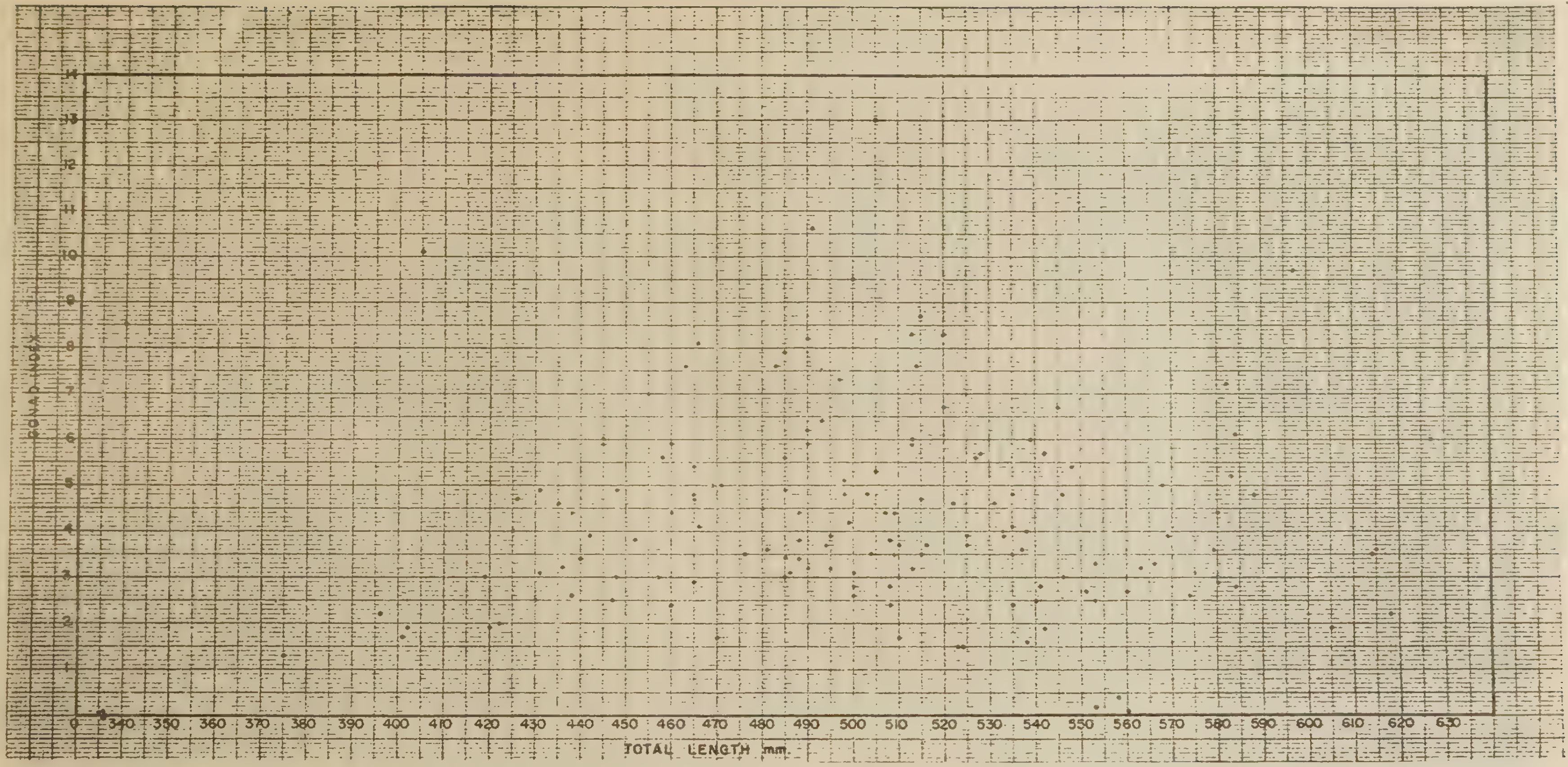

Figure 35. Gonad index of Katsuwonus pelamis caught by trolling (Baird and Gill) 1947 - 1949 in Philippine waters.

Since 77.12 percent of the total number of females caught had a gonad index greater than 3, it indicates that a greater percentage of breeding females were captured during the period of survey. It appears that the fish with the heaviest ovarian weight of 168.2 g has a total length of 505 mm with a gonad index of 13.06. Other examples of fish of varying length groups have gonad index ranges above 3, while some with lengths of more than 500 mm have a gonad index of less than 3. This may indicate that after spawning, the ovaries undergo a period of rest or regeneration for the next breeding season.

Table XV shows the distribution of gonad indices to months of capture for skipjack. For almost all months two groups of fish were available to the fishery; a breeding group with gonad index 3 and a greater and non-breeding group with gonad index less than 2. In fact in most months a gonad index of 5 to 8.7 is represented in almost all females captured throughout the year, indicating the extended breeding habit of the fish.

3.4.3 Yaito tuna

Figure 36 illustrates the distribution of lengths (total lengths) of yaito tuna to gonad index. As may be seen, fish from 330 mm to 380 mm total length are immature with gonad index less than 3 but from 385 mm total length the fish starts to show a gonad index of 3 or greater. As in the skipjack, mature fish may be found from 385 mm to 650 mm total length. The majority of the catch, however, were with lower gonad indices which may be correlated to non-spawning months when captured.

Table XVI shows that only 32.72 percent of the total females of the yaito tuna taken have a gonad index greater than 3. This is quite low compared with what was obtained from the skipjack. One fish (508 mm total length) has a gonad index of 16.8.

Table XVII shows the distribution of gonad indices of yaito tuna to months of capture. As may be seen a gonad index value of more than 3 is found during the greater part of the year, and the highest from March to May as was found in the case of the skipjack. Since two mean length groups were represented in the catch per month, one with gonad index above and another below 3, there appears a resorption of ova after breeding so that a longer fish may have a bigger gonad index.

3.4.4 Dogtooth and scaly tuna

Table XVIII shows the distribution of gonad indices of the dogtooth tuna and the scaly tuna both of which were rarely caught by trolling during the period of survey. Only six female dogtooth tuna were taken during the period and although they were from 519 mm to 760 mm total length all were immature.

Of the scaly tuna most of those taken were immature, for only two out of 16 females taken (430 mm to 660 mm total length) were with a gonad index of more than 3.

Table XIX gives the monthly distribution of the two species in relation of gonad indices. The number of specimens taken, however, prevents the author from forming any conclusion.

3.5 Catch localities of tunas by trolling

Inasmuch as trolling was done in the daytime in most cruises of the research vessels, and that the research vessels travelled in many parts of the country, plotting the areas where trolling was found to be succesful may help to determine the localities where the different species of tuna are plentiful.

Figures 37 to 40 show the trolling areas and the localities where trolling has been successful. The concentration of the catch in the southern part of the Philippines may be noted and the areas where the availability of these fish is much greater determined, confirming the well-known fact that there is a much greater concentration of the various species of tunas in localities nearer the equator than those farther from it.

4 SUMMARY AND CONCLUSIONS

1. A tuna exploration program of the Philippine Bureau of Fisheries using a 110-ton longliner from Japan, the M/V Malasugui made three exploratory fishing cruises during 1960 for deep-swimming tuna in the southern parts of the Philippines.

2. The tuna catches were mostly of yellowfin, bigeye, a few albacores, several species of spearfish and sharks.

EP/41

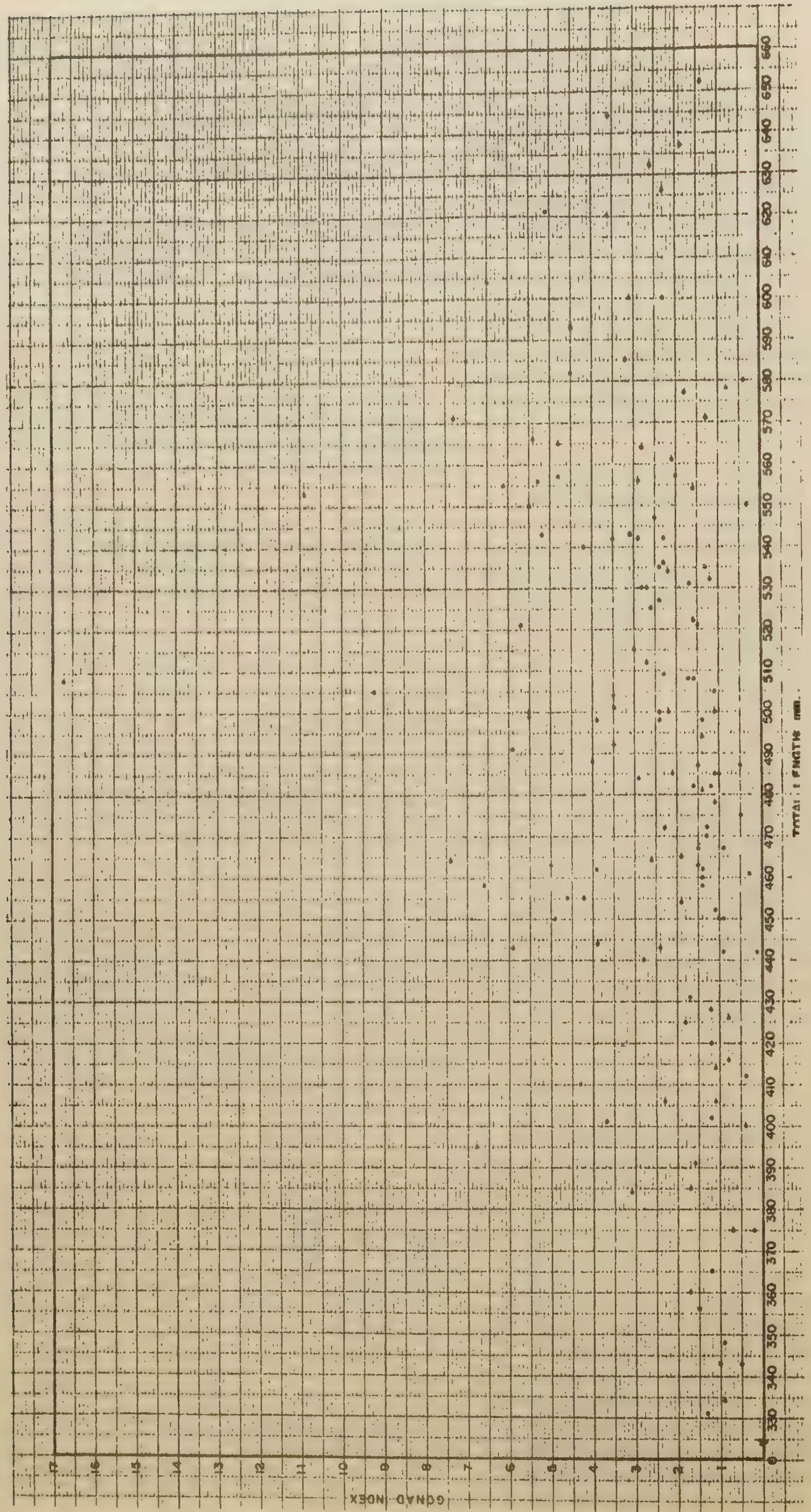

Figure 36. Gonad index of Euthynnus yaito caught by trolling (Baird, Gill and Jordan) 1947 - 1949 in Philippine waters.

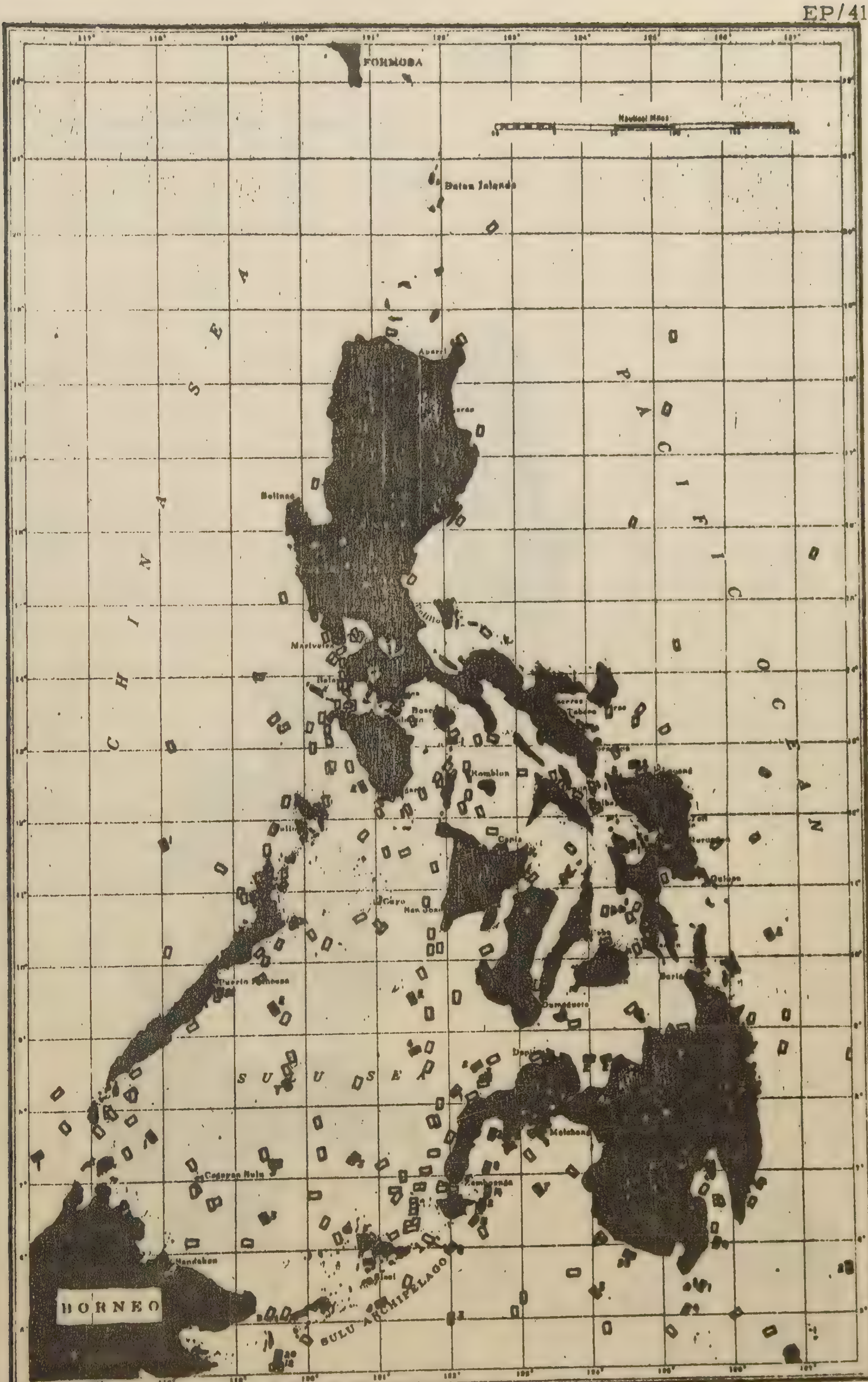
FORMOSA
Nautical Miles
Batan Islands
Aparri
Bolinao
Mariveles
CHINA SEA
PACIFIC OCEAN
Romblon
Capiz
Cuyo
San Jose
Puerto Princesa
Dumaguete
SULU SEA
Cagayan Sulu
Zamboanga
Sandakan
BORNEO
SULU ARCHIPELAGO

Figure 37. Successful trolling stations for Neothunnus macropterus taken by the S. F. Baird from 16 September, 1947 - 24 November, 1949.

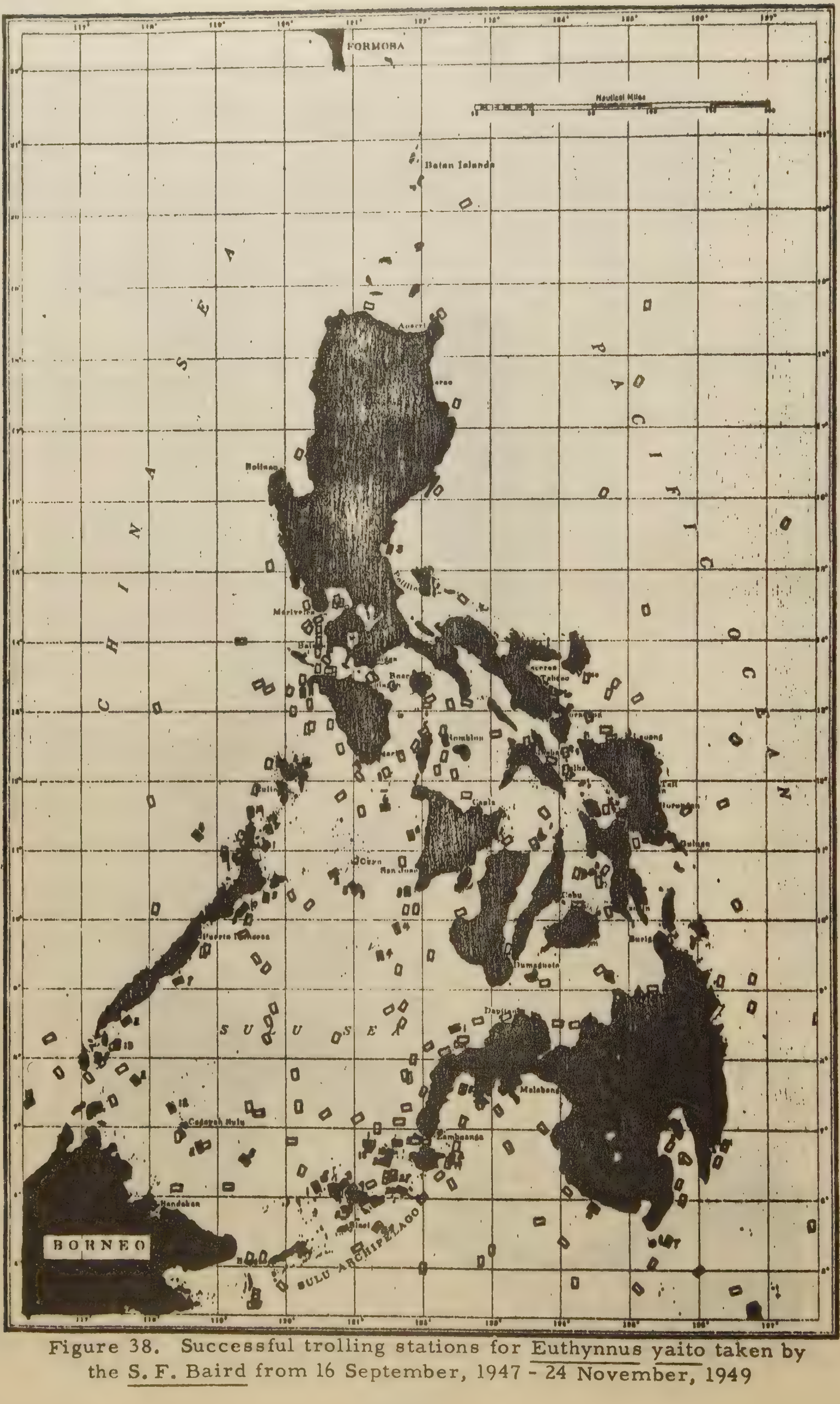
FORMOSA
Nautical Miles
Batan Islands
CHINA SEA
PACIFIC OCEAN
Bolinao
Mariveles
Romblon
Capiz
Cuyo
San Juan
Cebu
Dumaguete
Puerto Princesa
SULU SEA
Zamboanga
Malabang
Cagayan Sulu
Sandakan
BORNEO
SULU ARCHIPELAGO

Figure 38. Successful trolling stations for Euthynnus yaito taken by the S. F. Baird from 16 September, 1947 - 24 November, 1949

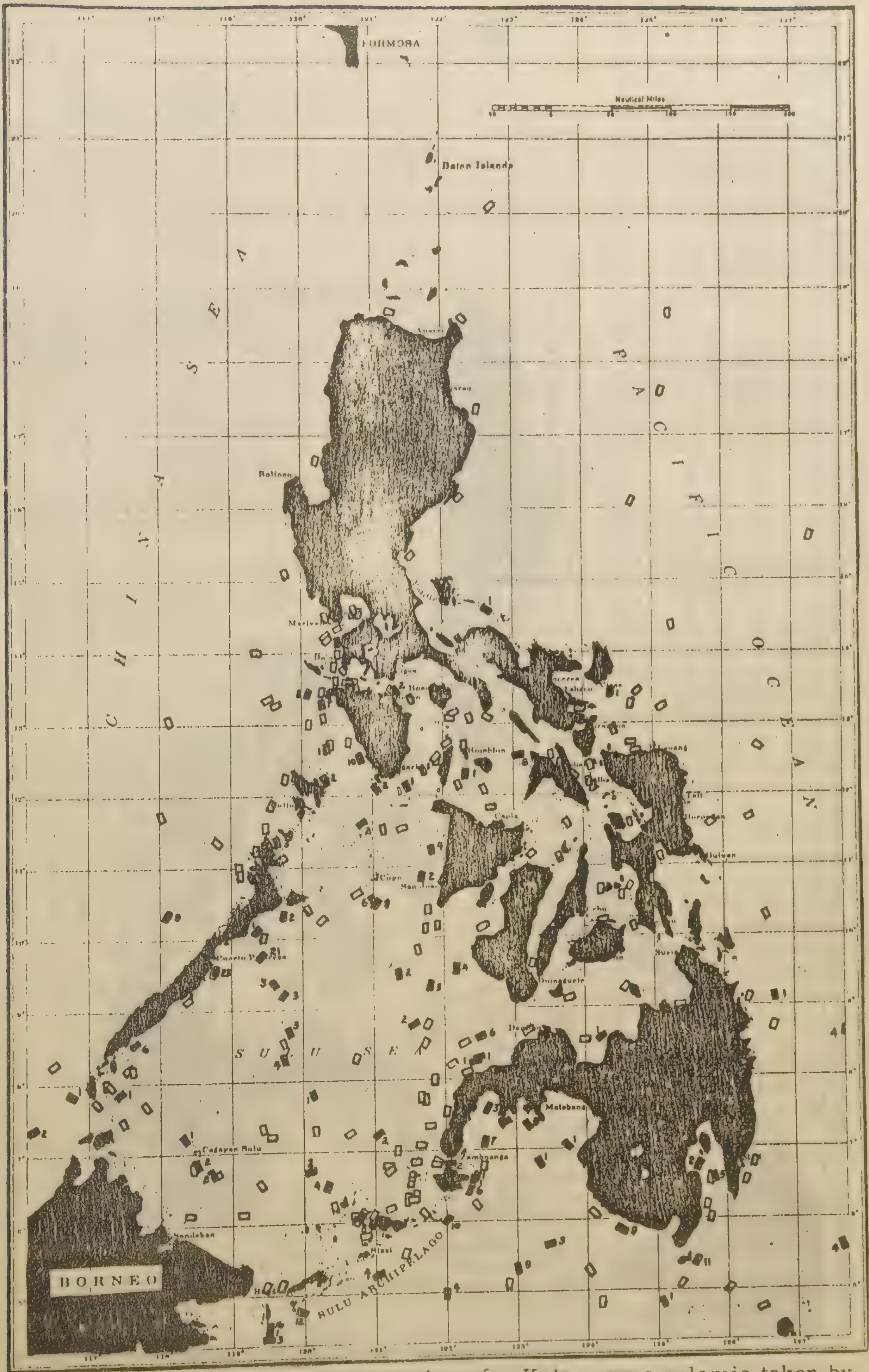
FORMOSA
Nautical Miles
Batan Islands
CHINA SEA
PACIFIC OCEAN
Bolinao
Romblon
Capiz
Cuyo
Puerto Princesa
SULU SEA
Cagayan Sulu
Zamboanga
Malabang
Sandakan
Siasi
SULU ARCHIPELAGO
BORNEO

Figure 39. Successful trolling stations for Katsuwonus pelamis taken by the S. F. Baird from 16 September, 1947 - 24 November, 1949.

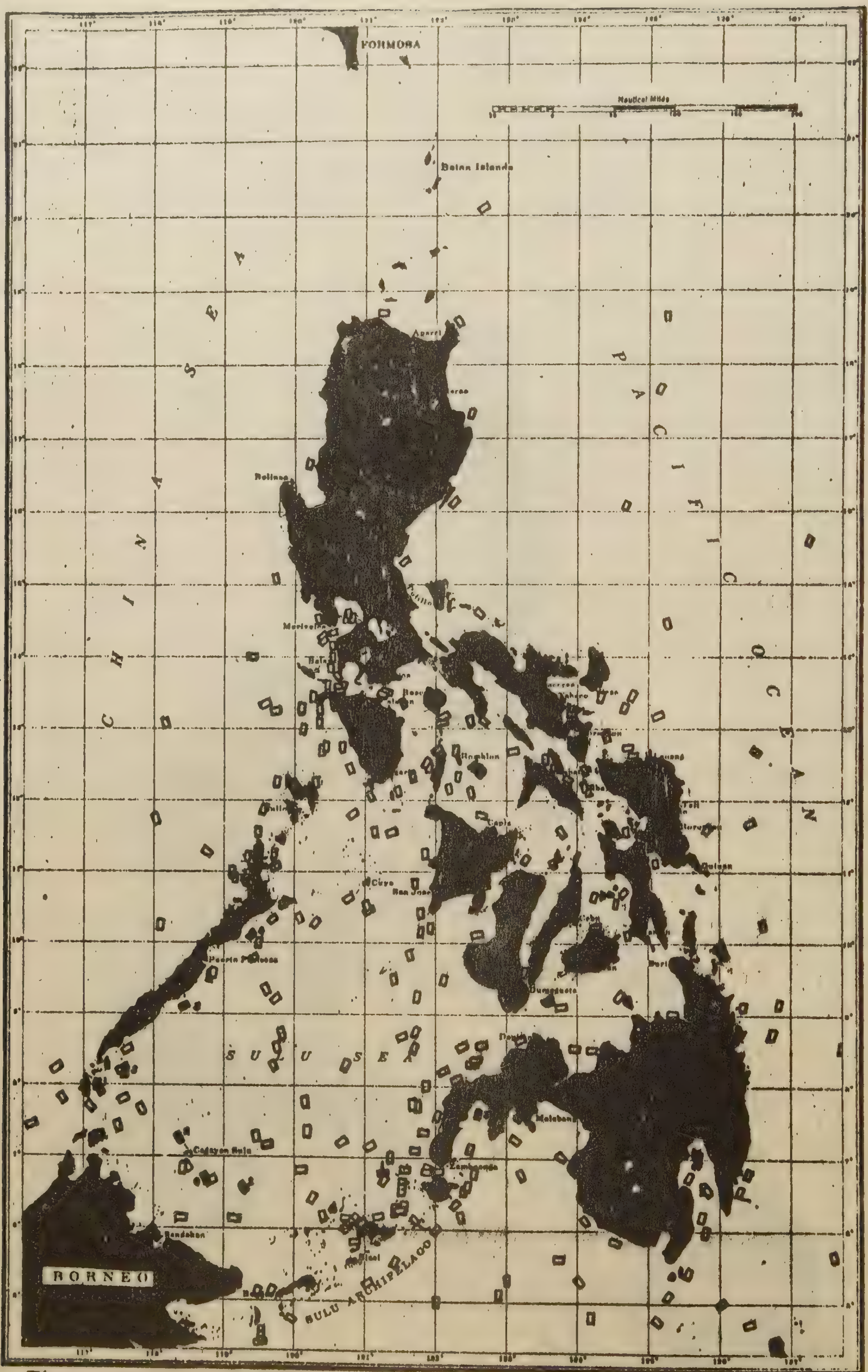
FORMOSA
Nautical Miles
Batan Islands
Aparri
Bolinao
CHINA SEA
PACIFIC OCEAN
Romblon
Capiz
Cuyo
San Jose
Puerto Princesa
Cebu
Dumaguete
Dapitan
SULU SEA
Malabang
Zamboanga
Cagayan Sulu
Sandakan
BORNEO
SULU ARCHIPELAGO

Figure 40. Successful trolling stations for Kishinoella tonggol taken by the S. F. Baird from 7 January, 1948 - 23 November, 1948.

3. The range in size of the yellowfin appears to indicate schooling by year classes as shown by mean total length of fish taken per operation.

4. The wide range in size of the bigeye appears to indicate that fish of several year classes are taken at the same time.

5. For all the three exploratory cruises of the Malasugui the yellowfin tuna predominated the catch. Furthermore, in the majority of the operations made, the male yellowfin predominated the females by not less that a 2 : 1 ratio.

6. The hook rates for the yellowfin, bigeye and albacore taken per hundred hooks were determined to be higher (3.03) for the first trip of the M/V Malasugui but low and similar for the second (1.99) and third trips (1.89).

7. The food habits of these fishes were analysed based on the contents of their stomachs. There is a very close similarity in the feeding habits of the yellowfin and the bigeye. About one-third of the food consists of fishes, one-third molluscs mostly squids and one-third crustacean decapods.

8. The food study of 109 yellowfin tuna revealed that the species seems to favour the carangids, snake mackerels and cutlass fish more than any other fish species for its diet. The squids and the decapods also form a big portion of its diet. On the other hand, the 15 bigeye tuna studied relished mostly the squids, while no particular fish group is preferred.

9. The trematode, Hirudinella ventriculosa (Pallas), was found common in both species of tuna.

10. The difference in the total gill raker count between the yellowfin (29.21) and the bigeye (27.29) lies in the mean number of gill rakers in the lower arch which is 20.27 for the yellowfin and 18.61 for the bigeye.

11. Based on the formula $W = kL^x$, the length-weight relationships for the yellowfin and bigeye tuna were taken. The length-weight data and the curves revealed that the slight differences between the k values and of the regression coefficients indicate that although a slight difference in the weight of the fish is noticeable between the sexes, an appreciable difference in weight does not exist.

Length-weight curves were fitted by the method of least squares with the resulting equations for males and females.

Yellowfin

Males: $W = 0.00002352\ L^{2.84682}$

Females: $W = 0.00004322\ L^{2.87651}$

Bigeye

Males: $W = 0.00004786\ L^{2.94430}$

Females: $W = 0.00001721\ L^{2.74669}$

W is the weight in kilograms and L is the length in millimetres.

12. The second part of the study is primarily a statistical comparison of the length-weight relations and gonad indices in relation to length of five species of Philippine tunas.

Studies on the skipjack, yellowfin, yaito tuna, dogtooth tuna and scaly tuna which were taken by the research vessels S. F. Baird, T. N. Gill and D. S. Jordan of the Philippine Fishery Program of the U.S. Fish and Wildlife Service from 1947 through 1949 were continued by determining the length-weight relationships separated into sexes for the first three species.

13. The monthly mean gonad indices of the five species of tuna were determined through the Kikawa method with the use of the formula gonad index = $Wo/L^3 \times 10^4$. In the yellowfin only 11.40 percent had a gonad index of 3 and greater, showing that mostly immature forms are available to trolling. Among the skipjacks, specimens with a length of 420 mm are mature and ready to spawn. The great majority of the skipjacks have gonad index from 3 to 8, as shown by almost all females captured throughout the year. This is indicative of an extended breeding habit of the fish.

14. In the case of yaito tuna, the majority of the specimens were with a gonad index lower than 3. However, those found with a gonad index of more than 3 were mostly captured from March to May, thus coinciding with the findings for the skipjack. For the dogtooth tuna and the scaly tuna, it is not safe to form any conclusion because the number of specimens studied was rather limited.

15. The gonad index study also showed that even after a fish has reached a minimum length representing length at first maturity with a gonad index of 3, the gonad may decrease in weight during the non-spawning season. This may be explained by the period of rest or regeneration undergone by the ovaries in preparation for the next breeding season.

16. The length-weight relations study of the troll-caught tuna showed the close relationship between the weights of a given size of the males and females of each species.

17. The troll catch per month of the different species of tuna by the research vessel S. F. Baird from 1947 through 1949 revealed that the months of March to July make up the tuna season in the Philippines inasmuch as the catch of skipjacks, yellowfins and yaito tuna is higher during this period than during the other months of the year.

18. The skipjacks and yaito tuna are more widely distributed over all Philippine waters than the dogtooth and scaly tunas which seem to be confined to a few fishing grounds in the southwestern part of the Philippines.

Experience Paper No. 42

DISTRIBUTION OF LARVAL TUNA COLLECTED BY THE CARLSBERG FOUNDATION'S DANA EXPEDITION (1928-30) FROM THE INDIAN OCEAN

By

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Abstract

The geographical and seasonal distribution of larvae of five species of tuna (*Katsuwonus pelamis*, *Neothunnus macropterus*, *Euthynnus affinis affinis*, *Auxis thynnoides* and *Auxis thazard*) in the Indian Ocean based mainly on the collections made by the 1928-30 *Dana* Oceanographical Expedition are dealt with.

Larvae of skipjack and yellowfin constitute the bulk of the larval tuna catches. Larvae of these two species seem to have a wide range of distribution in the tropical and sub-tropical parts of the Indian Ocean though not with uniform abundance. Most of the larvae were obtained from an area west of 50°E longitude between 0° - 25° S latitude. They were found to be abundant in the surface layers of the sea and the maximum numbers were collected from areas of high temperature ranging from 26°C to 29°C.

REPARTITION DES LARVES DE THONS RECOLTEES DANS L'OCEAN INDIEN PAR L'EXPEDITION OCEANOGRAPHIQUE DU *DANA*, DE LA FONDATION CARLSBERG (1928-30)

Résumé

Le document traite de la repartition géographique et saisonnière dans l'océan Indien des larves de cinq espèces de thon (*Katsuwonus pelamis*, *Neothunnus macropterus*, *Euthynnus affinis affinis*, *Auxis thynnoides* et *Auxis thazard*) en se fondant principalement sur les resultats de l'Expédition océanographique du *Dana* (1928-1930).

Le gros des récoltes de larves de thons porte sur les bonites à ventre rayé et les thons à nageoires jaunes. Les larves de ces deux espèces paraissent entre très largement reparties dans les zones tropicale et subtropicale de l'océan Indien, quoique leur abondance ne soit pas uniforme. La plupart des larves ont été prelevées dans une zone s'étendant à l'ouest du 50° de longitude Est, entre l'équateur et le 25e parallèle Sud. Elles se sont revelées entre abondantes dans les couches superficielles de la mer, les quantités maximales étant récoltees dans des zones de haute température (de 26 a 29° C).

DISTRIBUCION DE LAS LARVAS DE ATUN RECOGIDAS POR LA EXPEDICION DEL *DANA* DE LA CARLSBERG FOUNDATION (1928-30) EN EL OCEANO INDICO

Extracto

Trata de la distribución geografica y estacional de larvas de cinco especies de atunes (*Katsuwonus pelamis*, *Neothunnus macropterus*, *Euthynnus affinis affinis*, *Auxis thynnoides* y *Auxis thazard* en el Océano Indico, a base principalmente de las colecciones obtenidas por la Expedicion Oceanográfica del *Dana* en 1928-30.

El grueso de las capturas de larvas de atunes lo constituyeron las de barrilete y atún de aleta amarilla. Las larvas de estas dos especies parece que tienen un amplio margen de distribución en los sectores tropicales y subtropicales del Oceano Indico, aunque su abundancia no es uniforme. La mayoria de las larvas se obtuvieron en una zona situada el oeste de los 50° de longitud E, entre los 0° y 25° de latitud. Se observó que abundaban mucho en las capas superficiales del mar y las cantidades máximas se recogieron en zonas de elevada temperatura, que oscilaba entre los 26°C y los 29°C.

1 INTRODUCTION

The Dana Expedition of 1928-30 round the world covered the Indian Ocean from August 1929 to January 1930. Out of the material collected, the larval scombroids from stations 3905 to 3975 were placed at the disposal of the senior author by the Carlsberg Foundation and this is dealt with in a preliminary way in this account, incorporating all existing information available on the subject for this region. Out of a total of 71 stations from longitude 88°05'5E and latitude 4°44'N between Nicobar and Ceylon to longitude 18°37'E and latitude 35°42'S off Cape of Good Hope, 62 stations contained tuna larvae, numbering in all 2183. Part of the Indian Ocean collections made by the Dana Expedition from the eastern sector south of the Sunda Archipelago as far as Cocos Keeling and Christmas Islands, from the Straits of Malacca and Singapore and stations east of longitude 90°E, along with collections from the Pacific and Atlantic Oceans were placed at the disposal of the Pacific Oceanic Fishery Investigations, now Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii. The larval Euthynnus, Auxis, Parathunnus sibi, Thunnus germo, T. orientalis and Kishinoella tonggol from the above have already been worked out by Matsumoto (1959 and 1961).

The phenomenal development of the tuna fisheries in the high seas in recent years has brought in its wake several investigational problems aimed at a proper appraisal of this potential resource and the work carried out in the Pacific (Schaefer and Marr 1948, Wade 1950 and 1951, Mead 1951, Matsumoto 1958, 1959 and 1961, Strasburg 1960) within the last 15 years has helped to advance appreciably our knowledge of the distinguishing characters of larval and juvenile stages of this important group of fishes and their pattern of distribution. Being oceanic fishes the tunas have very wide distribution and most of the species occurring in the Indo-Pacific are common to both the oceans. The information we have on the early stages of tunas in the Indian Ocean is limited to the contributions of Jones (1959, 1960a and 1960b), Jones and Kumaran (1962), Yabe and Ueyanagi (1961) and Bogorov and Rass (1961).

Identification of some of the larvae was rendered difficult as the collections examined were made over 30 years ago and as juveniles were scarce. The chromatophores in many had faded considerably and a number of specimens were either damaged or not in a good state of preservation. From the material available the authors have been able to distinguish larvae of five species of tunas - Katsuwonus pelamis, Neothunnus macropterus, Euthynnus affinis affinis, Auxis thazard and Auxis thynnoides. Since other species of tunas are also known to occur in the Indian Ocean, the possibility of the early larval stages of some others getting mixed up with the above cannot be entirely ruled out in spite of all efforts to avoid such a contingency. The present account deals with the geographical, seasonal and vertical distribution of tuna larvae in the Indian Ocean based on the information available so far

2 GEOGRAPHICAL AND SEASONAL DISTRIBUTION

2.1 The oceanic skipjack Katsuwonus pelamis (Linnaeus)

1083 larval and postlarval stages of the oceanic skipjack Katsuwonus pelamis measuring in total length from 3.1 mm to 24.9 mm, forming almost 50 percent of the total tuna larvae were obtained between stations 3905 and 3975 during the cruise of the research ship Dana in the Indian Ocean. In Table 1 the localities of capture, surface temperature, size range of the specimens etc., are given. Areas of capture of larvae inclusive of all other previous records are plotted in Fig. 1. Seasonal occurrence of larvae is given in Table 7. It could be seen that most of the larvae were obtained during the months of December and January from the western Indian Ocean, whereas 40 larvae were obtained during November from the northern Indian Ocean. Considering the capture of larvae per hour of plankton haul, a fairly extensive area along the track of the Dana between the Seychelles and Durban seems to be an important spawning area of this species. The most southern record of occurrence of larvae is at station 3972 (36°09'S, 21°52'E). Even though skipjack larvae were obtained all along the course of the Dana in varying degrees of abundance, it is presumed that spawning of skipjack is intensive in the tropical and sub-tropical parts of the western Indian Ocean between 3°S - 30°S latitude.

Table 1
Details of collection of larvae of Katsuwonus pelamis

[illegible] (1)	[illegible] (2)	Position (3)	Surface temperature (4)	No. of specimens (5)	Size range in mm (6)
[illegible]	[illegible]	[illegible]	-	2	7.14-12.50
[illegible]	[illegible]	[illegible]	28.0	9	4.85-7.36
[illegible]	[illegible]	[illegible]	-	6	5.15-10.45
[illegible]	[illegible]	[illegible]	-	6	4.85-6.74
[illegible]	[illegible]	[illegible]	-	15	4.75-9.87
[illegible]	[illegible]	[illegible]	-	6	4.79-12.56
[illegible]	[illegible]	[illegible]	-	15	5.59-7.39
[illegible]	[illegible]	[illegible]	29.3	22	5.28-7.42
[illegible]	[illegible]	[illegible]	-	2	7.02-7.36
[illegible]	[illegible]	[illegible]	28.8	19	5.99-8.45
[illegible]	[illegible]	[illegible]	-	24	4.22-27.57
[illegible]	[illegible]	[illegible]	-	10	4.45-12.55
[illegible]	[illegible]	[illegible]	30.4	7	5.19-7.25
[illegible]	[illegible]	[illegible]	-	35	4.91-9.42
[illegible]	[illegible]	[illegible]	28.6	7	5.59-8.50
[illegible]	[illegible]	[illegible]	28.2	1	6.88
[illegible]	[illegible]	[illegible]	-	17	4.75-7.90
[illegible]	[illegible]	[illegible]	-	1	damaged
[illegible]	[illegible]	[illegible]	27.3	9	4.06-6.55
[illegible]	[illegible]	[illegible]	-	1	5.22
[illegible]	[illegible]	[illegible]	-	50	4.66-13.36
[illegible]	[illegible]	[illegible]	-	1	6.28
[illegible]	[illegible]	[illegible]	-	5	4.11-7.25
[illegible]	[illegible]	[illegible]	-	2	damaged
[illegible]	[illegible]	[illegible]	-	4	4.96-9.82
[illegible]	[illegible]	[illegible]	27.9	6	5.31-5.93
[illegible]	[illegible]	[illegible]	-	23	3.93-8.16
[illegible]	[illegible]	[illegible]	-	2	5.3-7.75
[illegible]	[illegible]	[illegible]	-	106	4.58-9.50

Table I (contd.)

(1)	(2)	(3)		(4)	(5)	(6)
3942	25-12-29	6°47'S	41°27'E	28.2	7	6.62-10.10
3943	25-12-29	5°30'S	40°40'E	-	33	4.33-12.73
3944	26-12-29	4°45'S	40°10'E	-	9	5.02-7.19
3946	3-1-30	3°26'S	42°58'E	-	31	3.82-9.07
3948	6-1-30	10°45'S	41°57'E	27.5	7	6.62-16.78
3949	6-1-30	11°33'S	41°44'E	-	2	5.99 & 12.45
3950	7-1-30	12°23'S	41°43.5'E	-	10	4.85-8.05
3951	7-1-30	14°16'S	41°48'E	-	7	7.53-10.33
3953	8-1-30	16°12'S	42°04'E	27.9	40	3.71-7.88
3954	9-1-30	16°53'S	42°12'E	-	42	5.13-16.73
3955	9-1-30	18°30'S	42°18'E	-	19	3.14-7.86
3956	10-1-30	21°13'S	42°26'E	27.9	63	4.22-24.93
3957	11-1-30	21°30'S	42°32'E	-	27	4.39-10.62
3958	11-1-30	23°11'S	42°54'E	-	7	4.85-19.27
3959	12-1-30	23°40'S	42°54'E	26.6	116	3.65-15.58
3960	13-1-30	25°23'S	42°52'E	26.0	18	4.16-14.78
3961	14-1-30	24°57'S	40°18'E	-	36	4.73-9.87
3962	14-1-30	24°33'S	38°26'E	26.5	18	5.62-15.36
3963	15-1-30	24°30'S	37°48.5'E	-	1	9.02
3964	15-1-30	25°14'S	36°21'E	28.6	76	4.11-8.45
3965	17-1-30	28°18'S	33°49'E	26.3	12	5.08-6.73
3969	27-1-30	31°33'S	30°07'E	-	38	5.36-9.19
3970	28-1-30	34°07'S	27°38'E	24.0	4	9.02-11.47
3971	29-1-30	35°49'S	23°09'E	24.2	13	5.99-11.19
3972	30-1-30	36°09'S	21°52'E	23.4	2	damaged
3974	31-1-30	35°42'S	19°51'E	20.9	1	damaged
3975	31-1-30	35°42'S	18°37'E	21.0	1	damaged

EP/42

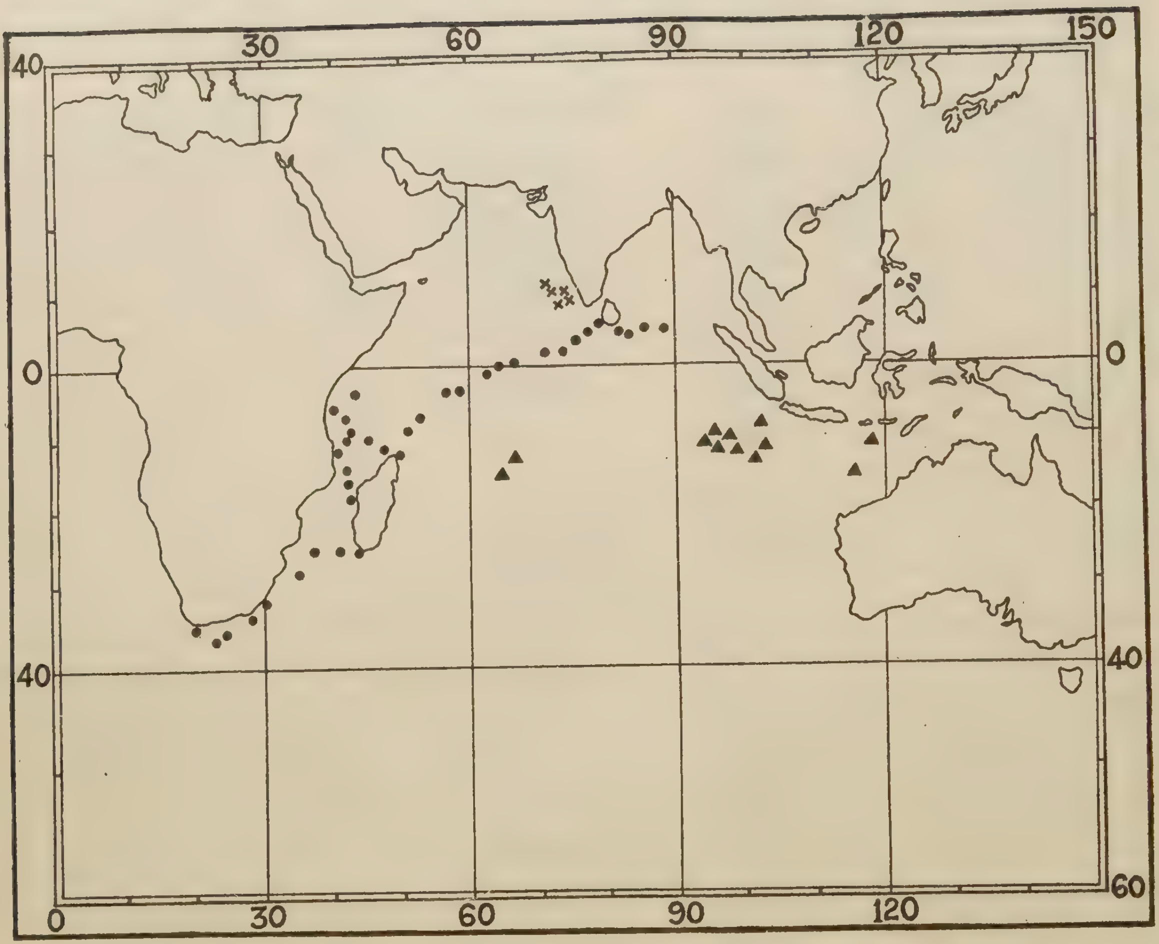
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Fig. 1 Localities of capture of larval oceanic skipjack (Katsuwonus pelamis)

● Dana collection; X Indian collection;

▲ Japanese collection.

Larvae were collected from the eastern and central Indian Ocean during January-February and June-July (Yabe and Ueyanagi 1961). Most of these collections were made during February. It has been stated by Bogorov and Rass (1961) that the existence of numerous spawning schools of N. macropterus, K. pelamis and A. thazard is indicated by the presence of larval tunas in some parts of the Indian Ocean. The localities of capture of larval tunas as given by them are shown in Fig. 5. Larvae were collected from an area south of Sumatra and Java during October and from the central part of the Indian Ocean during November and December. Their total absence in the collections of the Vityaz from the western part of the Indian Ocean remains to be explained. During the months of December to April, 30 specimens ranging in length from 2.63 mm to 7.08 mm have been collected from the Laccadive Sea (Jones 1959). The period of occurrence of larvae is observed to correspond with the presence of adult with mature and spent ovaries in the Laccadive Sea. Skipjack landings in Minicoy usually show an increase during January and February. The most northern record of occurrence of skipjack larvae in the Indian Ocean is near Chetlat Island (11°70'N, 72°65'E) in the Laccadives (Jones 1959) during the month of April. It is evident from these observations that larvae are abundant during November to April between 0° - 12°N latitude and during November to February in the western Indian Ocean between 0° - 30° S latitude. The data available so far do not permit the authors to infer whether there is any difference in the spawning seasons between skipjack populations of the different parts of the Indian Ocean. According to Wade (1951) breeding of skipjack occurs throughout the year in Philippine waters, the peak spawning period being October to April. Capture of larvae was found to be high in the tropical and subtropical Pacific (Yabe and Ueyanagi, 1961) and this holds almost true for the condition prevailing in the western Indian Ocean. The possibility of occurrence of spawning in the tropical Indian Ocean throughout the year as in the Pacific cannot be ruled out as intensive collections have not been made from the area so far.

2.2 The yellowfin tuna Neothunnus macropterus (Temminck and Schlegel)

745 yellowfin larvae ranging in size from 3.4 mm to 19 mm were available for study. This comes to about 34 percent of the total catch of tuna larvae. In Table 2 the details of stations where larvae were captured are given. Larvae have been collected from mid-ocean and very near to land. From the northern Indian Ocean, 5 specimens were obtained in November. The maximum recorded (541 larvae) was from the western Indian Ocean west of 50°E, between 0° - 12°S. Of the above, 266 were obtained in a single haul from station No. 3941 (7°24'S, 41°51'E) situated south-east off Mombasa. Number of larvae in the collections gradually declined towards the south. Localities of capture of larvae are indicated in Fig. 2.

Spawning of yellowfin takes place during February to April in the Laccadive Sea as evidenced by the capture of 36 larvae from the area (Jones 1959). Yabe and Ueyanagi (1961) have shown the localities of collection of larvae from the Indian Ocean. It would appear from the above that there is a concentration of larvae in the low latitudinal areas of the eastern Indian Ocean east of 94°E between latitudes 8°S to 15°S but the months of capture of larvae have not been indicated by them.

Larvae were collected by the Vityaz (Bogorov and Rass 1961) from the eastern and northern Indian Ocean during October to January. It is supposed from the available data that spawning occurs in the tropical and subtropical parts of the Indian Ocean during October to April. Spawning of yellowfin was observed to take place throughout the year in the tropical Pacific (Yabe and Ueyanagi 1961). The fishery for Neothunnus macropterus in the northern and western parts of the Indian Ocean is high during the months of January to May. As mature fish are present in the area as evidenced by the length frequency data presented by Japanese workers (Mimura 1958, Tsuruta and Tsunoda 1960) it is presumed that some spawning occurs during the above period.

EP/42

Table II
Details of collection of larvae of Neothunnus macropterus

Dana stations (1)	Date (2)	Position (3)		Surface temperature (4)	No. of specimens (5)	Size range in mm (6)
3908	22-11-29	4° 28'N	82° 13'E	-	1	9.25
3910	23-11-29	5° 28'N	80° 00'E	-	3	5.53-5.59
3912	24-11-29	6° 52'N	79° 30'E	28.2	1	12.04
3914	2-12-29	4° 52'N	77° 08'E	-	36	5.59-7.42
3915	3-12-29	3° 14'N	75° 21'E	29.3	19	5.25-7.93
3916	4-12-29	1° 45'N	73° 03'E	-	3	5.94-7.93
3917	5-12-29	1° 45'N	71° 05'E	28.8	11	5.02-8.10
3918	7-12-29	0° 35'N	66° 09'E	-	1	5.08
3919	8-12-29	0° 07'S	63° 56'E	-	4	5.93-11.54
3921	11-12-29	3° 36'S	58° 19'E	-	8	4.33-7.93
3927	17-12-29	10° 55'S	50° 15'E	-	30	4.05-9.47
3928	18-12-29	11° 20'S	50° 10'E	27.3	13	4.62-8.05
3929	18-12-29	12° 11'S	50° 18'E	-	2	4.22-6.85
3932	20-12-29	11° 35'S	49° 45'E	-	2	6.45
3934	20-12-29	11° 24'S	50° 05'E	-	5	5.02-7.99
3935	21-12-29	10° 50'S	48° 30'E	-	2	6.91-8.22
3936	22-12-29	10° 28'S	47° 30'E	-	1	4.45
3937	22-12-29	9° 26'S	46° 05'E	-	1	7.48
3938	23-12-29	9° 10'S	45° 17'E	27.9	1	5.77
3939	23-12-29	8° 44'S	43° 54'E	-	29	4.91-8.62
3940	24-12-29	8° 24'S	42° 54'E	-	8	4.79-8.51
3941	24-12-29	7° 24'S	41° 51'E	-	266	3.94-10.50

Table II (contd.)

(1)	(2)	(3)		(4)	(5)	(6)
3942	25-12-29	6°47'S	41°27'E	28.2	14	4.45-8.73
3943	25-12-29	5°30'S	40°40'E	-	47	5.53-9.71
3944	26-12-29	4°45'S	40°10'E	-	40	5.31-19.01
3946	3-1-30	3°26'S	42°58'E	26.7	12	5.48-8.96
3948	6-1-30	10°45'S	41°57'E	27.5	4	4.39-8.10
3949	6-1-30	11°33'S	41°44'E	-	2	damaged
3950	7-1-30	12°23'S	41°43.5'E	-	2	5.88-8.22
3951	7-1-30	14°16'S	41°48'E	-	18	6.38-9.71
3953	8-1-30	16°12'S	42°04'E	27.3	16	4.45-6.62
3954	9-1-30	16°53'S	42°12'E	-	25	4.11-10.85
3955	9-1-30	18°30'S	42°18'E	-	38	3.37-9.47
3956	10-1-30	21°13'S	42°26'E	27.9	42	5.12-9.31
3957	11-1-30	21°30'S	42°32'E	-	6	4.57-10.11
3959	12-1-30	23°40'S	42°54'E	26.6	6	6.16-10.39
3960	13-1-30	25°23'S	42°52'E	26.0	15	5.53-10.33
3962	14-1-30	24°33'S	38°26'E	26.5	1	6.28
3963	15-1-30	24°30'S	37°48.5'E	-	1	7.59
3964	15-1-30	25°14'S	36°21'E	28.6	9	5.13-10.89
3969	27-1-30	31°33'S	30°07'E	-	2	6.85-7.94

EP/42

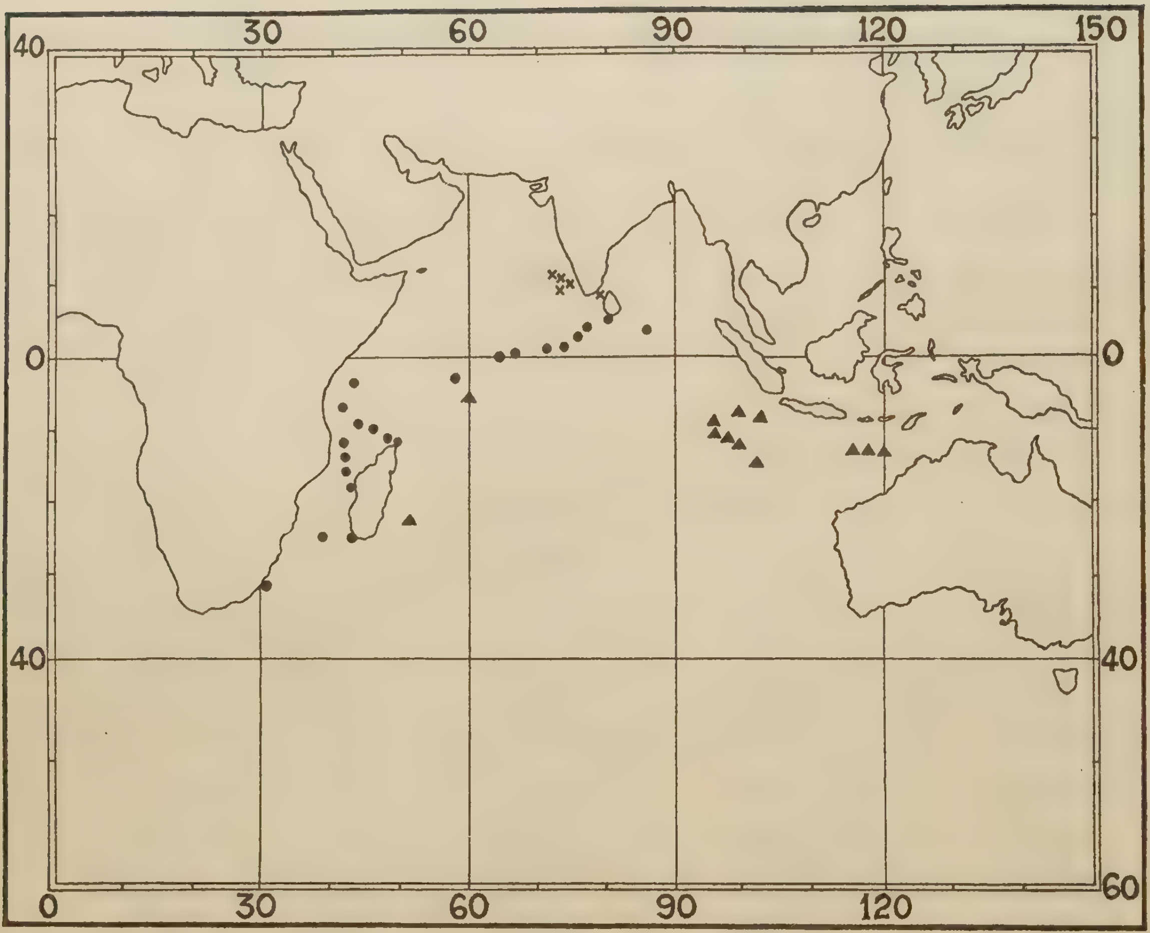
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Fig. 2 Localities of capture of larval yellowfin (Neothunnus macropterus)
● Dana collection; X Indian collection;
▲ Japanese collection.

2.3 The little tunny *Euthynnus affinis affinis* (Cantor)

There are 179 larvae ranging in size from 4.6 mm to 12.7 mm supposed to be of this species in the collection. Details of localities of capture of larvae are given in Table III. In the northern Indian Ocean larvae of this species were rarely obtained during the time of the cruise but they were taken in good numbers in the western Indian Ocean between 3°S to 25°S latitude where some spawning appears to take place during December and January. Most of the specimens were collected in the vicinity of land. Even though the fishery for this species is restricted to coastal areas, a few larval specimens were obtained from offshore areas. Matsumoto (1959) has examined 61 larval specimens collected by the *Dana* from the eastern part of the Indian Ocean near Sunda Archipelago during August-October which he considers as of *Euthynnus yaito*. In Fig. 3 the localities of capture of *Euthynnus* larvae are indicated. In this connection it may be stated that the species of *Euthynnus* occurring in Indonesian waters is considered to be *affinis*, the type of which was described from Malaya by Cantor (1850). *E. yaito* of the Pacific may be a different geographical race of *E. affinis* and it is possible that the seas between Indonesia and the Philippines may be an area of mixing of the two races.

2.4 The long corseletted frigate mackerel *Auxis thynnoides* Bleeker

20 larval specimens tentatively identified as *A. thynnoides* ranging in size from 5 mm to 11.5 mm were obtained during December and January from three stations between the island of Madagascar and the African coast. The details of capture of larvae are given in Table IV and the localities of capture including all former records of *Auxis* larvae from the Indian Ocean are plotted in Fig. 4. Two types of *Auxis* larvae have been reported to be present in the collections made by the *Dana* from the eastern Indian Ocean southwest off Sunda Archipelago during August to November (Matsumoto 1959). According to Yabe and Ueyanagi (1961) spawning occurs during May to July near Japan and during January to February in the Celebes Sea and the south China Sea. Low latitudinal areas of the eastern Indian Ocean southwest off Sunda Archipelago and the western Indian Ocean between Madagascar and the mainland of Africa are assumed to be good spawning areas of *A. thynnoides*. However, the data presently available are too meagre to draw definite conclusions about the spawning of this species in the Indian Ocean.

2.5 The short corseletted frigate mackerel *Auxis thazard* (Lacépède)

There are 131 larvae of this species ranging in total length from 4.6 mm to 11.2 mm in the material examined by the authors. Table V gives details of stations where larvae were captured. One larva was obtained in December from the northern Indian Ocean the location being 4°52'N, 77°08'E. Almost all the specimens were obtained from an area west of 50°E between 3°S and 24°S during December and January. It appears that most of the *Auxis* larvae collected by the *Dana* from the eastern part of the Indian Ocean (Matsumoto 1959) belong to this species. For reasons given elsewhere (Jones 1962b) the larval *Auxis* obtained from the Laccadive Sea during January and April (Jones 1960b) belong to *A. thazard*. Bogorov and Rass (1961) have indicated the presence of spawning schools of *A. thazard* in the Indian Ocean. It is therefore reasonable to assume that the species has an extended spawning period in the Indian Ocean from August to April, but data are not available for the rest of the year.

It has been observed (Matsumoto 1959) that *Auxis* is a more "pelagic spawner" than *Euthynnus* as indicated by the capture of larvae from the central Pacific and Atlantic. This view is corroborated by the capture of larvae of *A. thynnoides* from the Indian Ocean relatively far from land.

2.6 *Thunnus* spp.

25 larvae presumably of *Parathunnus sibi* (*P. mebachi*), and *Kishinoella tonggol* were obtained from the western Indian Ocean. Table VI gives the details of collection of these larvae. Good catches of bigeye *Parathunnus sibi* have been reported from the western Indian Ocean (Nankai

EP/42

Table III
Details of collection of larvae of *Euthynnus affinis affinis*

Dana Stations (1)	Date (2)	Position (3)		Surface temperature (4)	No. of specimens (5)	Size range in mm (6)
3917	5-12-29	1°45'N	71°05'E	28.8	1	7.08
3918	7-12-29	0°35'N	66°09'E	-	1	damaged
3922	12-12-29	3°45'S	56°33'E	28.6	2	6.05-7.14
3924	14-12-29	5°01'S	54°46'E	-	1	5.94
3926	16-12-29	8°27'S	50°54'E	-	1	5.59
3930	19-12-29	11°55'S	49°55'E	-	2	4.7 damaged
3931	19-12-29	12°09'S	49°34'E	-	8	6.62-12.72
3938	23-12-29	9°10'S	45°17'E	27.9	1	6.58
3940	24-12-29	8°24'S	42°54'E	-	3	5.14-7.94
3941	24-12-29	7°24'S	41°51'E	-	56	4.68-8.73
3944	26-12-29	4°45'S	40°10'E	-	15	5.42-12.16
3946	3-1-30	3°26'S	42°58'E	26.7	34	4.74-8.69
3947	4-1-30	4°21'S	42°56'E	-	2	6.11 damaged
3951	7-1-30	14°16'S	41°48'E	-	3	6.79 damaged
3953	8-1-30	16°12'S	42°04'E	27.9	14	4.79-9.14
3955	9-1-30	18°30'S	42°18'E	-	1	damaged
3956	10-1-30	21°13'S	42°26'E	27.9	3	5.65-5.88
3958	11-1-30	23°11'S	42°54'E	-	2	7.08-8.39
3964	15-1-30	25°14'S	36°21'E	28.6	29	4.62-7.42

Table IV
Details of collection of larvae of *Auxis thynnoides*

Dana stations	Date	Position		Surface temperature	No. of speci-	Size range in mm
3940	24-12-29	8°24'S	42°54'E	-	1	damaged
3946	3-1-30	3°26'S	42°58'E	26.7	18	5.02-11.48
3955	9-1-30	18°30'S	42°18'E	-	1	8.28

Table V
Details of collection of larvae of *Auxis thazard*

Dana stations	Date	Position		Surface temperature	No. of specimens	Size range in mm
3914	2-12-29	4°52'N	77°08'E	-	1	5.65
3925	16-12-29	7°13'S	52°22'E	28.2	1	6.79
3931	19-12-29	12°09'S	49°34'E	-	15	5.42-11.23
3946	3-1-30	3°26'S	42°58'E	26.7	103	4.74-11.13
3947	4-1-30	4°21'S	42°56'E	-	1	7.76
3955	9-1-30	18°30'S	42°18'E	-	4	4.62-7.59
3958	11-1-30	23°11'S	42°54'E	-	2	6.11-8.39
3959	12-1-30	23°40'S	42°54'E	26.6	3	.8.85
3966	18-1-30	29°25'S	32°00'E	23.7	1	9.93

EP/42

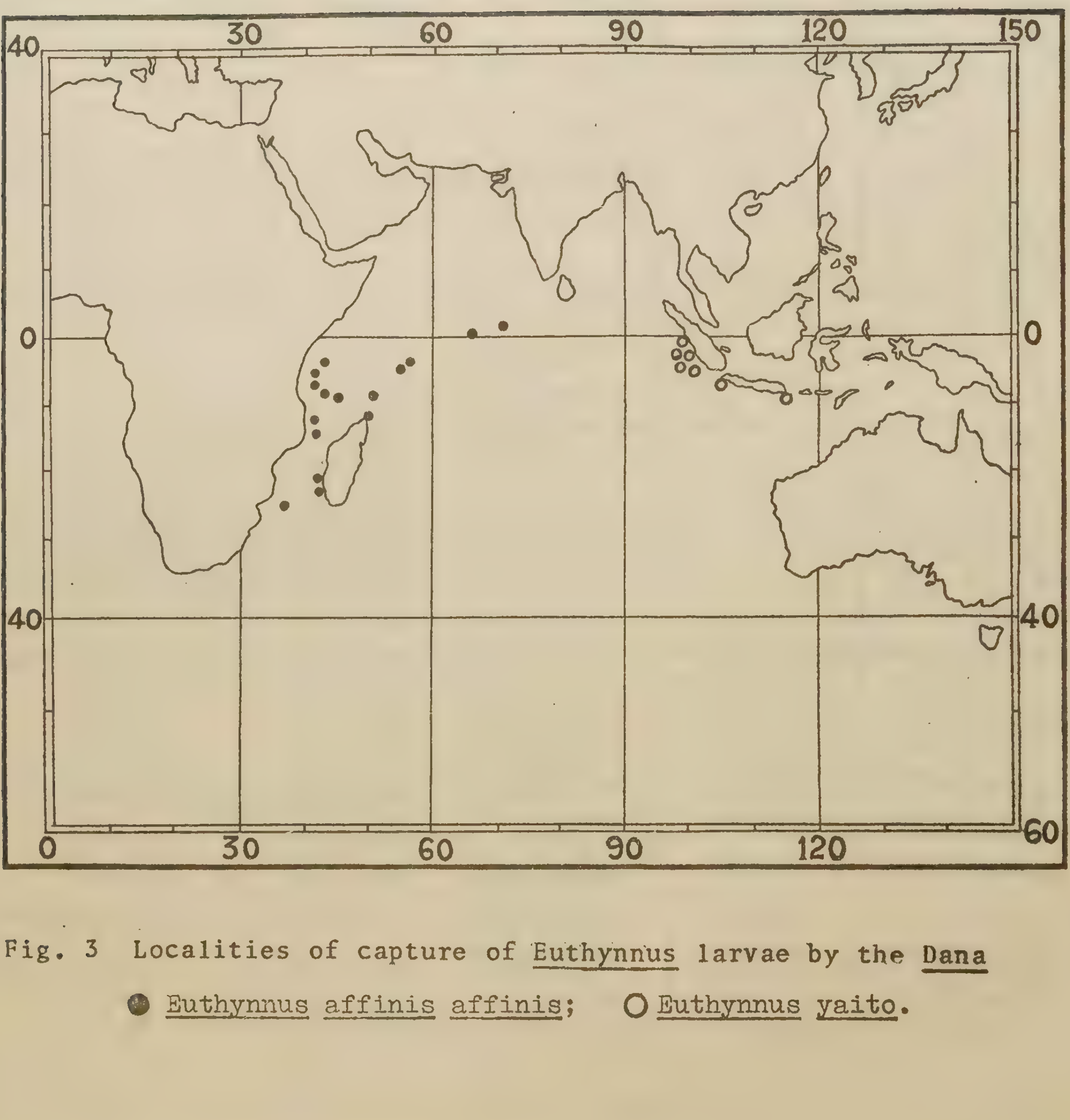
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Fig. 3 Localities of capture of Euthynnus larvae by the Dana

● Euthynnus affinis affinis; ○ Euthynnus yaito.

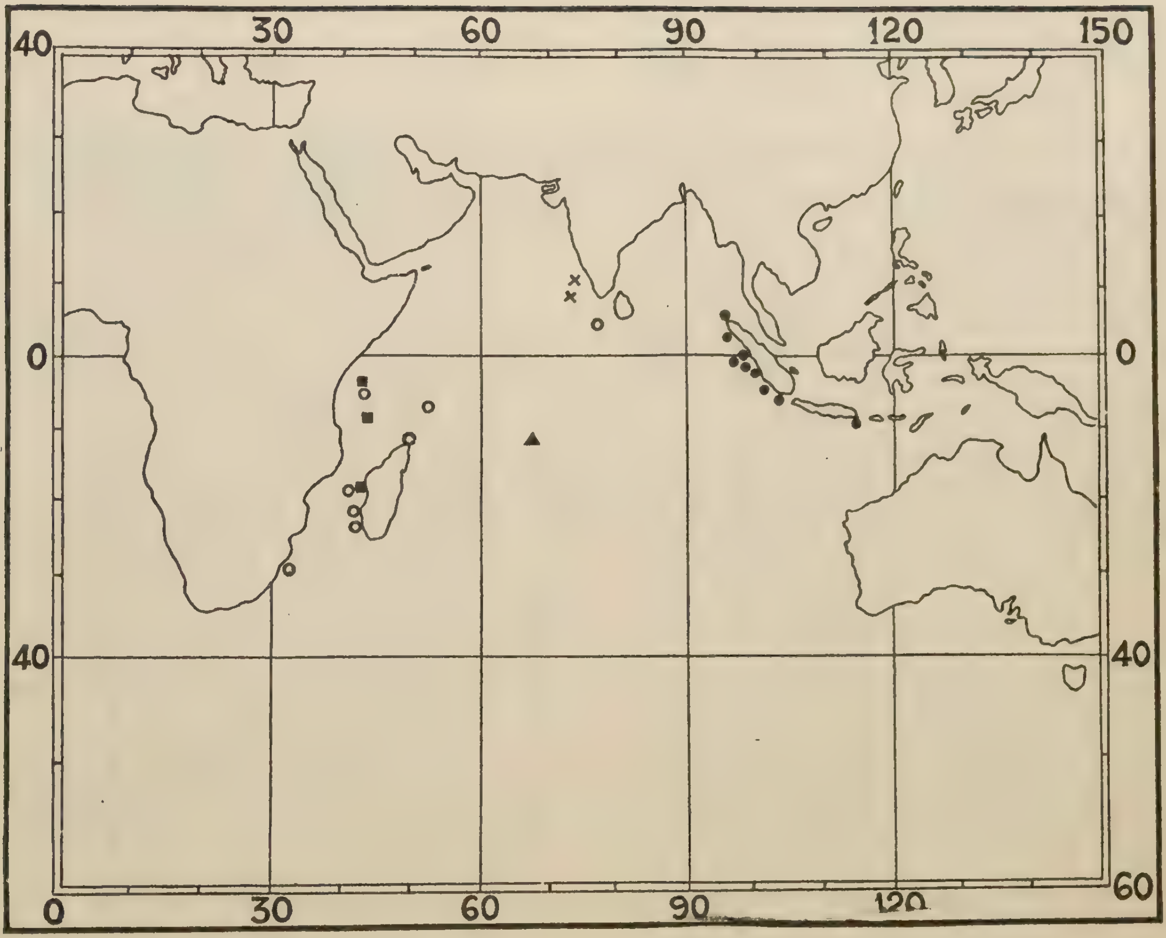
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Fig. 4 Localities of capture of Auxis larvae

○ Dana collection (A. thazard); × Indian collection (A. thazard);
■ Dana collection (A. thynnoides); ▲ Japanese collection
(A. thynnoides); ● Dana collection (Auxis spp., after
Matsumoto 1959).

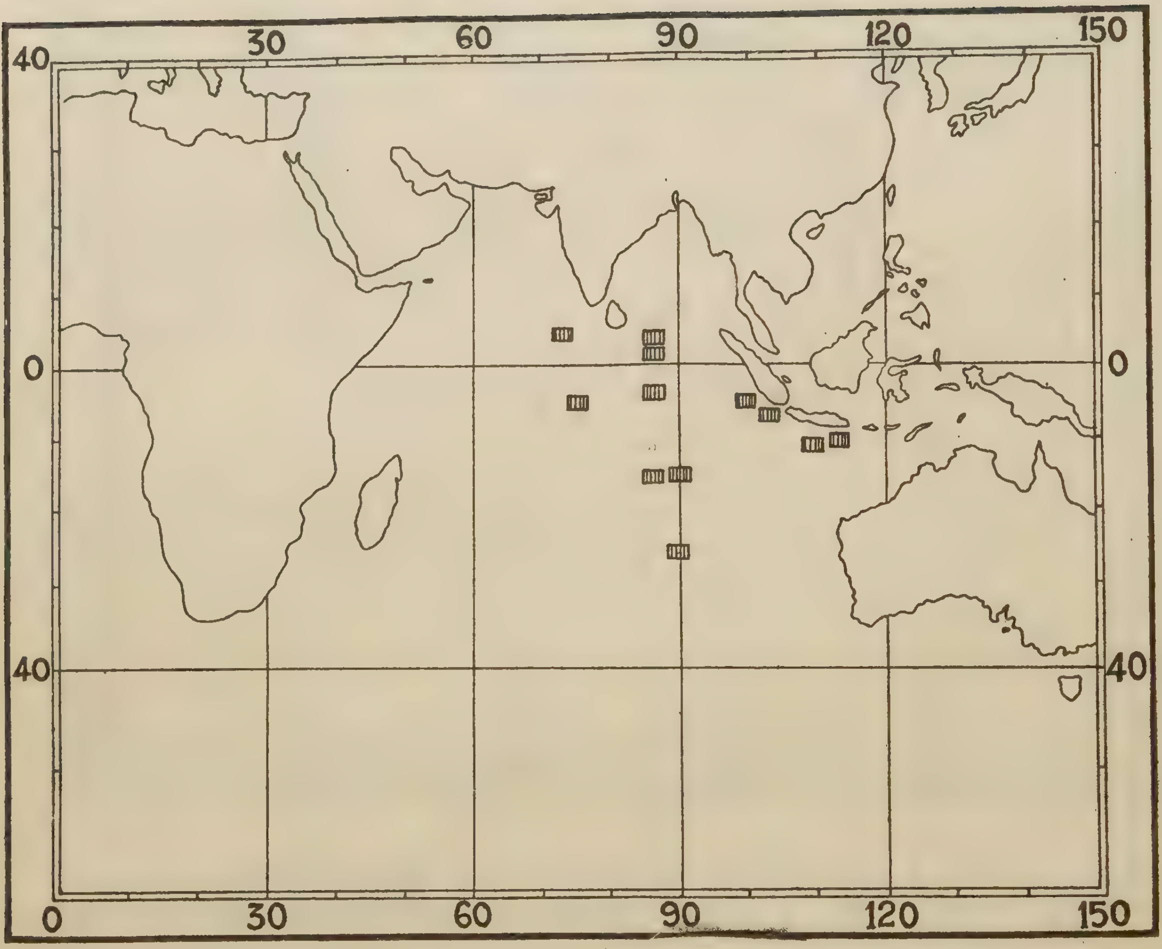
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Fig. 5 Localities of capture of tuna larvae by the *Vityaz* (after Bogorov and Rass 1961)

Regional Fisheries Research Laboratory 1959).

3 VERTICAL DISTRIBUTION

The method adopted by Tåning (1955) has been followed here to find out the number of fishing hours and the depth of plankton tows. Number of fishing hours and the number of specimens obtained per hour of plankton haul at different depths are given in Table VIII 72 percent of the larvae were captured in nets operated in the upper 30 m and it was found that the percentage of capture of larvae decreases with depth. As open type nets were used, the actual percentage of capture of larvae from the surface layers must be higher than 72 percent as it is possible that an appreciable number of larvae found in nets operated in the lower layers were obtained while the nets were being raised. The percentage of capture of larvae per hour of haul from the lowest layer was insignificant. Matsumoto (1959) has shown that tuna larvae make a vertical, diurnal migration through relatively shallow depths and that most of the larvae occur near the surface both during day and night. According to Yabe and Ueyanagi (1961) tuna larvae occur rarely in the surface layer during the day but are distributed abundantly in the midlayer below 20 m and their distribution is more or less uniform in the upper 50 m layer during the night. Increase in larval catches with increase in depth in subsurface waters during the day was suggested to be mainly on account of the downward migration and to a limited extent on reduction in the amount of dodging with decrease in illumination (Strasburg 1960). It could be presumed that a comparatively higher percentage of larvae of Katsuwonus pelamis inhabits the lower layers (vide Table VIII).As almost all the collections were obtained during the night, the data for day and night hauls have not been analysed separately. However, percentage of capture of larvae was found to be less in the collections made in the early morning and just after sunset.

4 DISCUSSION

The information we have at present on the distribution of larval tunas in the Indian Ocean is too incomplete to warrant any conclusions. The specimens obtained by the Dana were only incidental in the course of the general plankton collections made during the expedition and collections by other agencies also do not give adequate coverage to the area in relation to space and time, though those by the Vityaz, the details of which are lacking, appear to be comparatively more intensive. However, certain indications which are evident from the available data are mentioned below.

It is obvious that environmental factors such as temperature, currents, salinity, nearness to land and availability of food may influence the nature of distribution, abundance and survival of larvae to a great extent. Surface water temperatures in areas where larvae were collected ranged from 20.9°C to 30.4°C. Percentage of capture of larvae at stations where temperature ranged from 26°C to 29°C was found to be high and so it is assumed that active spawning occurs in areas of fairly high temperature. These temperature ranges for larval tuna distribution in the Indian Ocean are in general agreement with the range 24.5°C to 29.0°C for the collection of Euthynnus larvae and the range of 22.5°C to 29.0°C for Auxis larvae given by Matsumoto (1959). In this connection the area west of longitude 50°E between 3°S to 20°S latitude deserves special mention. More larvae per haul were obtained from there than from anywhere else and a look at the temperature chart (Fig. 7) would show that this region has the highest temperature viz., 29°C to 29.5°C than any other area in the open Indian Ocean. The Mozambique Channel which is influenced considerably by the warm waters of the Agulhas Current flowing towards the south appears to be another area of abundance of tuna larvae. The western Indian Ocean as a whole has been reported to be rich in tuna by the Japanese. However, the absence of any tuna larvae in the Vityaz collections (Bogorov and Rass 1961) in this region requires explanation. Since the cruise of the Vityaz in that region was during March-April as against December-January by the Dana it is presumed that spawning is slack during this period in that area.

Probably the most important factor that influences the temperature and consequently the spawning activity of tuna and distribution of their larvae is the current system. The surface currents of the Indian Ocean (Fig. 6) are subjected to seasonal variations due to different winds. Most of the areas in the western part of the Indian Ocean where larvae were abundant are under the influence of the Equatorial Currents which flow in a westerly direction and bring about upwelling near the East African coast (Sverdrup et al, 1942) where primary production also is reported to be high (Kabanova 1961). It would therefore appear that the abundance of larvae west of 50°E longitude during December and January is due to the congregation of spawners in the warm water of this area. Currents should also play an important part in the dispersal of the larvae. According to Matsumoto (1958), spawning of tuna occurs in areas of north and south Equatorial Currents in the Pacific and the displacement of the early larvae caused by the flow of the currents is estimated to be about 2°.

Tunas are known to congregate in areas of high productivity. No detailed information is available at present about the zooplankton distribution in the area during different months of the year and as such no definite conclusions can be drawn with regard to the relation, if any, existing between the zooplankton abundance and occurrence of larvae.

Areas of very low salinity are generally avoided by tunas. Salinity variations in the open ocean are not marked (Fig. 8) and such slight variations do not seem to influence the distribution pattern of either the adults or the larvae.

It is natural to expect a relation between the abundance of larvae and that of the spawners. Larvae have been obtained from most of the areas where good catches of tuna have been reported by the Japanese (Nankai Regional Fisheries Research Laboratory 1959). However, the abundance of larvae in some of the areas where there is no regular fishing for tuna at present indicates that they could form potential tuna fishing grounds.

Table VI
Details of collection of unidentified tuna larvae

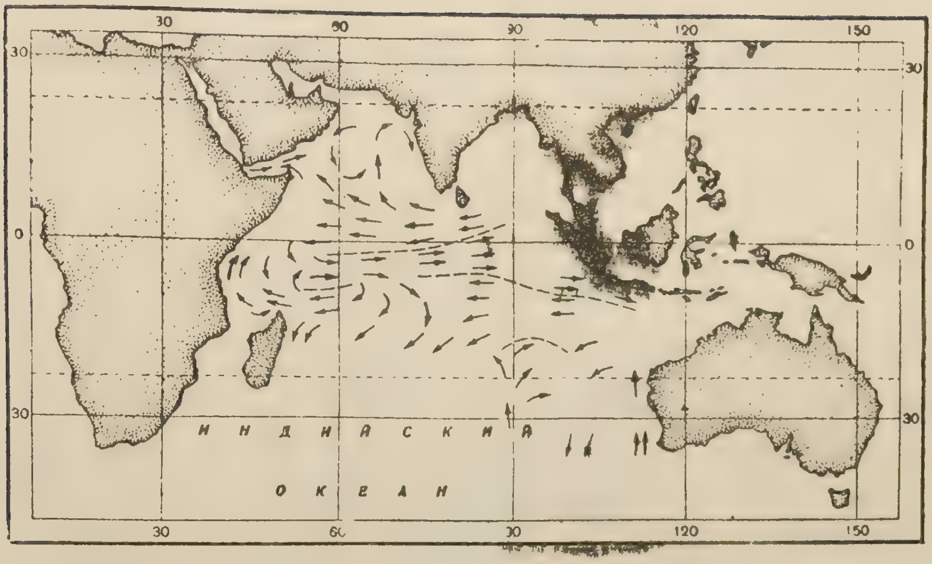
Dana station	Date	Position	Surface temperature	No. of speci-mens	Size range in mm
3922	12-12-29	3°45'S 56°33'E	28.6	12	6.28-8.11
3926	16-12-29	8°27'S 50°54'E	-	1	damaged
3928	18-12-29	11°20'S 50°10'E	27.3	1	6.17
3931	19-12-29	12°09'S 49°34'E	-	1	7.48
3937	22-12-29	9°26'S 46°05'E	-	2	4.85-4.91
3969	27-1-30	31°33'S 30°07'E	-	8	5.71-8.27

Table VII
Monthly distribution of tuna larvae (*Dana*)

	Month			Total
	November	December	January	
Katsuwonus pelamis	40	452	591	1083
Neothunnus macropterus	5	541	199	745
Euthynnus affinis affinis	-	91	88	179
Auxis thynnoides	-	1	19	20
Auxis thazard	-	17	114	131
Unidentified tuna larvae	-	17	8	25

Table VIII
Distribution of larval tunas according to depth of haul (*Dana* collections)

Depth of haul in metres	No. of fishing hours	*K. pelamis*		*N. macropterus*		*E. affinis affinis*		*A. thynnoides*	
		No. of specimens	No. per one hour of haul	No. of specimens	No. per one hour of haul	No. of specimens	No. per one hour of haul	No. of specimens	No. per one hour of haul
0-Ca. 20	38	323	8.5	219	5.8	41	1.1	5	0.1
Ca. 30	82	350	4.3	387	4.7	111	1.4	106	1.3
Ca. 50-70	62	261	4.2	70	1.1	13	0.2	15	0.2
Ca. 100-200	245	152	0.6	69	0.3	14	0.1	5	0.02


30
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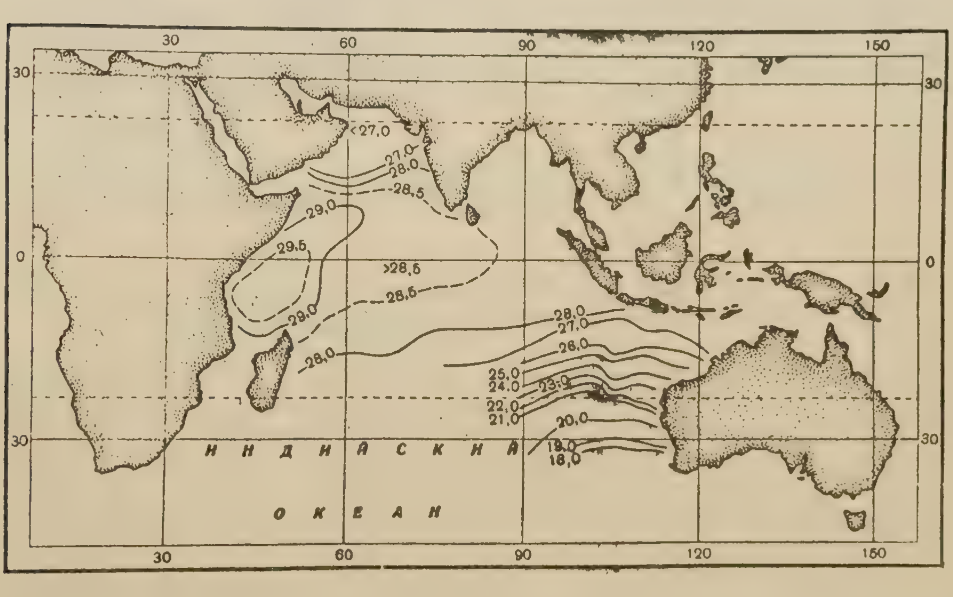
ИНДИЙСКИЙ
ОКЕАН

Fig. 6. Currents of the Indian Ocean at a depth of 15 m
(reproduced from Ovchinnikov 1961)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ИНДИЙСКИЙ
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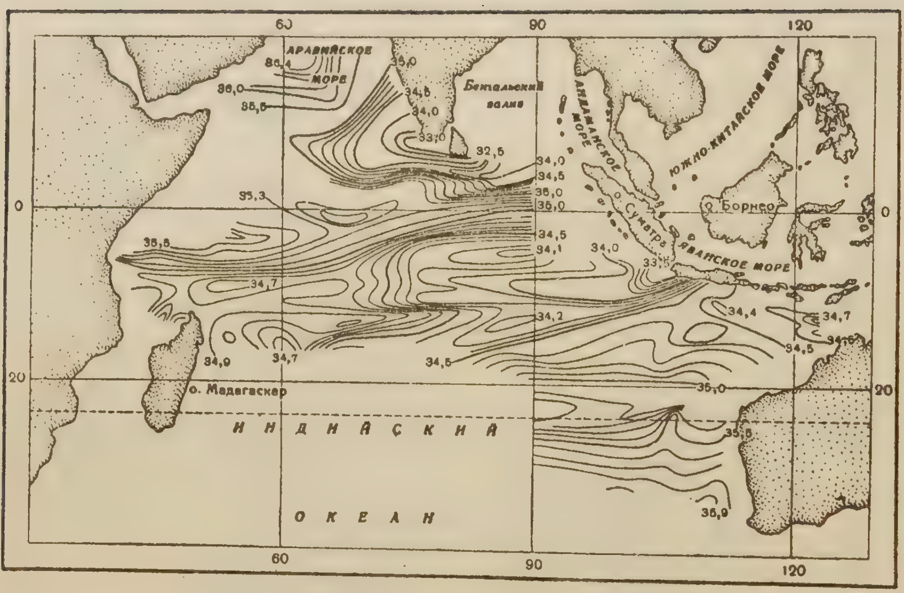
Fig. 7. Temperature distribution of water at the surface
(reproduced from Lukyanov and Moiseyev 1961)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АРАВИЙСКОЕ
МОРЕ
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Бенгальский
залив
АНДАМАНСКОЕ
МОРЕ
ЮЖНО-КИТАЙСКОЕ МОРЕ
о. Борнео
о. Суматра
ЯВАНСКОЕ МОРЕ
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34,5
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34,5
35,0
о. Мадагаскар
ИНДИЙСКИЙ
ОКЕАН
35,5
35,9

Fig. 8. Surface salinity of the Indian Ocean (reproduced from Ivanov-Frantzkevitch 1961)

Experience Paper No. 43

TUNA AND TUNA-LIKE FISHES FROM THE INDIAN SEAS

By

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Abstract

An account of the tuna and tuna-like species from the Indian Ocean and contiguous seas is given along with a tentative key for their identification. Regional references for each species and subspecies, as well as pertinent synonyms are included. The species and subspecies dealt with are: *Grammatorcynus bicarinatus* (Quoy and Gaimard); *Auxis thazard* (Lacépède); *Auxis thynnoides* Bleeker; *Cybiosarda elegans* Whitley; *Sarda orientalis* (Temminck and Schlegel); *Gymnosarda unicolor* (Rüppell); *Thunnus (T.) thynnus orientalis* (Temminck and Schlegel); *Thunnus (T.) alalunga* (Bonnaterre); *Thunnus (Parathunnus) obesus sibi* (Temminck and Schlegel); *Kishinoella tonggol* (Bleeker); *Thunnus (Neothunnus) albacares macropterus* (Temminck and Schlegel); *Thunnus (Neothunnus?) itosibi* Jordan and Evermann; *Allothunnus fallai* Servanty; *Katsuwonus pelamis* (Linnaeus); and *Euthynnus affinis affinis* (Cantor).

THONS ET ESPECES VOISINES DES EAUX INDIENNES

Résumé

La communication traite des thons et espèces voisines de l'océan Indien et des mers contiguës, et fournit une clef provisoire pour leur identification. Pour chaque espèce et sous-espèce sont données les références régionales ainsi que les synonymes pertinents. Les espèces et sous-espèces en question sont les suivantes: *Grammatorcynus bicarinatus* (Quoy et Gaimard); *Auxis thazard* (Lacépède); *Auxis thynnoides* Bleeker; *Cybiosarda elegans* Whitley; *Sarda orientalis* (Temminck et Schlegel); *Gymnosarda unicolor* (Ruppell); *Thunnus (T.) thynnus orientalis* (Temminck et Schlegel); *Thunnus (T.) alalunga* (Bonnaterre); *Thunnus (Parathunnus) obesus sibi* (Temminck et Schlegel); *Kishinoella tonggol* (Bleeker); *Thunnus (Neothunnus) albacares macropterus* (Temminck et Schlegel); *Thunnus (Neothunnus?) itosibi* Jordan et Evermann; *Allothunnus fallai* Servanty; *Katsuwonus pelamis* (Linnaeus); *Euthynnus affinis affinis* (Cantor).

EP/43

ATUNES Y PECES AFINES DE LOS MARES DE LA INDIA

Extracto

Se hace una reseña de los atunes y peces afines del Oceano Indico y mares contiguos, a la vez que se presenta una clave provisional para su identificación. Se incluyen asimismo referencias regionales correspondientes a las especies y subespecies así como los sinónimos correspondientes. Las especies y subespecies de que trata son: *Grammatorcynus bicarinatus* (Quoy y Gaimard); *Auxis thazard* (Lacepede); *Auxis thynnoides* Bleeker; *Cybiosarda elegans* Whitley; *Sarda orientalis* (Temminck y Schlegel); *Gymnosarda unicolor* (Ruppell); *Thunnus* (*T.*) *thynnus orientalis* (Temminck y Schlegel); *Thunnus* (*T.*) *alalunga* (Bonnaterre); *Thunnus* (*Parathunnus*) *obesus sibi* (Temminck y Schlegel); Kishinoella *tonggol* (Bleeker); *Thunnus* (*Neothunnus*) albacares macropterus (Temminck y Schlegel); Thunnus (Neothunnus?) itosibi Jordan y Evermann; *Allothunnus fallai* Servanty; *Katsuwonus pelamis* (Linnaeus); *Euthynnus affinis affinis* (Cantor).

1 INTRODUCTION

The comparative study of scombroid fishes by Kishinouye (1923) has contributed a great deal to our knowledge of tunas and related fishes in the Indo-Pacific and it still remains the most comprehensive account on the subject though the species dealt with were those found in Japanese waters. The last twenty years have, however, seen several attempts to straighten out the nomenclature of tuna and tuna-like fishes from various parts of the world (Serventy, 1941, 1956; Godsil and Byers, 1944; Brock, 1949; Fraser-Brunner, 1950; Godsil and Holmberg, 1950; Schaefer and Walford, 1950; Rosa, 1950; de Beaufort, 1951; Rivas, 1951, Ginsburg, 1953; Godsil, 1954; de Sylva, 1955; Bullis and Mather, 1956 and several others). Yet the picture that emerges out of all this is one of vagueness, though some understanding has been achieved in regard to the recognition of certain species in the Atlantic and in the Pacific. Conflicting views are held regarding the higher categories.

At the informal Pacific Tuna Biology Conference held at Honolulu, Hawaii, in August 1961 two contributions which have direct bearing on taxonomy and nomenclature of tunas were presented. Of these, Collette (1961) while recognising six species of tunas proper, relagated Neothunnus, Parathunnus and Kishinoella, recognised by many workers as distinct genera (Kishinouye, 1923; Jordan and Evermann 1926, etc.) or subgenera (Fraser-Brunner, 1950, Rivas 1961 etc.) to the absolute synonym of Thunnus remarking that the differences between these are only of specific importance. Roedel and Fitch (1961) on the other hand, speaking of the commercially important species of tunas, namely, the albacore, bluefin, bigeye, yellowfin and skipjack, drew attention to the inadequacies in our present understanding of the species problem in tunas as we are still unaware whether in each case we are dealing with a single world-wide species, perhaps separable into sub-species; or whether we are concerned with several geographically limited species, themselves perhaps divisible into sub-species. Unless efforts are made to solve this problem, it will be hard to obtain unanimity on any conclusion regarding recognition of species or races of tunas. As a tentative suggestion, until the problem can be tackled on a global basis, Roedel and Fitch (1961) have followed the course of suppressing Germo to the synonym of Thunnus, while retaining Parathunnus, Neothunnus and Kishinoella as separate genera, and so also Katsuwonus, Euthynnus and Auxis.

At the symposium on "Scombroid fishes" held at Mandapam Camp in January 1962, the authors (Jones and Silas, 1962a) have drawn attention to the desirability of having one or more centres where good series of scombroid material from different regions could be accummulated for comparative study and reference, which would also enable elucidation of the species problem in tuna and tuna-like fishes on a global basis. A preliminary account of Indian tunas was given by Jones and Silas (1960) and other notable recent contributions on the systematics of tunas of the Indian Ocean in general are those by Talbot (1962) from South African waters; Williams (1962) from East African coast; Fourmanoir and Crosnier (1962) from Madagascar; Baissac (1962) from Mascarene waters and Whitley (1962) from Australian waters.

In the light of the authors' investigations and those mentioned above, the following are recognised from the Indian Ocean. (Table I)

The precise identity of some of the species from the Indian Ocean is lacking as shall be shown presently for the bluefin, bigeye etc. However, current names used are based on the result of logical deductions, the validity of which will be known only when the species are studied on a world-wide basis.

Some nomenclatorial discussions are given on tuna and tuna-like fishes recognised by the authors from the Indian Ocean. Detailed discussions are given by Jones and Silas (1962a). A key for the identification of the species mentioned here is given below.

EP/43

Table I
TUNAS FROM THE INDIAN OCEAN

Common name	Genus	Sub-genus
Tunas - Proper		
Albacore	Thunnus	Thunnus
Bluefin	Thunnus	Thunnus
Bigeye	Thunnus	Parathunnus
Yellowfin	Thunnus	Neothunnus
Northern bluefin	Kishinoella	
Skipjack	Katsuwonus	
Little tunny or mackerel tuna	Euthynnus	
Slender tunny	Allothunnus	
Tuna-like fishes		
Bonito	Sarda	
Frigate mackerel	Auxis	
Dogtooth tuna	Gymnosarda	
Leaping bonito	Cybiosarda	
Double-lined mackerel	Grammatorcynus	

2 TENTATIVE KEY TO THE IDENTIFICATION OF TUNAS AND RELATED FISHES FROM THE INDIAN OCEAN

1a. Corselet obscure; two lateral lines, an upper and a lower, latter commencing from former in a line below anterior part of first dorsal and deeply decurved following lower contour of body, eventually joining upper lateral line near peduncular keel; vertebrae 31.

Grammatorcynus bicarinatus (Quoy and Gaimard)

1b. Corselet well developed; lateral line single 2

2a. First and second dorsal fins widely separated by distance exceeding length of base of first dorsal 3

2b. First and second dorsal fins contiguous or separated by only a narrow interspace not exceeding diameter of orbit 4

3a. Corselet scales abruptly taper immediately below end of first dorsal and continue as a very narrow band having not more than four or five rows of scales in a line below second dorsal; total gill rakers about 39-42 (mean 39.8)

Auxis thazard (Lacépède)

3b. Corselet scales gradually taper behind first dorsal and continue as a wide band with 7 to 12 rows of scales in a line below seventh dorsal finlet; total gill rakers about 40-47 (mean 44.8)

Auxis thynnoides Bleeker

4a. Distance from tip of snout to end of maxilla 50 percent or more of head length; end of maxilla surpasses vertical below middle of orbit 5

4b. Distance from tip of snout to end of maxilla considerably less than 50 percent of head length; end of maxilla does not surpass vertical below middle of orbit 7

5a. Vomer with villiform teeth; dorsal and anal finlets 9 or 10/7 or 8

Cybiosarda elegans Whitley

5b. Vomer edentulous; dorsal and anal finlets 6 to 8/ 5 or 6 6

6a. Dorsal with 18 or 19 spines; end of maxilla surpassing vertical below posterior border of orbit; 6 to 9 horizontal dark stripes on upper half of body appear as short broken bars in juveniles

Sarda orientalis (Temminck and Schlegel)

6b. Dorsal with 12-14 spines; end of maxilla reaching to vertical below posterior third of orbit; no dark stripes on body.

Gymnosarda unicolor (Rüppell)

7a. Body completely scaled; those of corselet and lateral line usually larger 8

7b. Body naked except for corselet and lateral line (exception Allothunnus) 13

8a. Anterior insertion of second dorsal nearer to posterior end of caudal keel than to posterior margin of orbit 9

8b. Anterior insertion of second dorsal nearer posterior margin of orbit than to posterior end of caudal keel 11

9a. Pectoral short, not exceeding head length excluding snout and falling short of vertical below anterior insertion of second dorsal by distance equalling almost its own length; preoperculum distinctly rounded along posterior margin.

Thunnus (T.) thynnus orientalis (Temminck and Schlegel)

9b. Pectoral elongate, one to one and a half times length of head and surpasses vertical below anterior insertion of second dorsal; preoperculum more or less angular at lower posterior margin. 10

10a. Gill rakers on lower limb 19 to 21; surface of liver markedly striated; vent rounded; distance between tip of pectoral and end of caudal keel much less than head length.

Thunnus (T.) alalunga (Bonnaterre)

10b. Gill rakers on lower limb 16 to 18; liver marked with faint striations on margin only; vent elliptical; distance between tip of pectoral fin and end of caudal keel greater than head length.

Thunnus (Parathunnus) obesus sibi (Temminck and Schlegel)

11a. Total gill rakers 19-26 of which 13-19 on lower limb (generally 15 to 17); air bladder absent; finlets with hardly any yellow being predominantly dusky.

Kishinoella tonggol (Bleeker)

11b. Total gill rakers 27-32 of which 19 to 22 on lower limb (generally 20-22); air bladder present; finlets lemon yellow with narrow dusky edging 12

12a. Pectoral surpassing vertical below anterior insertion of second dorsal; anal and second dorsal not elongate and shorter than pectoral.

Thunnus (Neothunnus) albacares macropterus (Temminck and Schlegel)

12b. Pectoral falls short of vertical below anterior insertion of second dorsal; anal and second dorsal greatly elongate, being considerably longer than pectoral.

Thunnus (Neothunnus?) itosibi (Jordan and Evermann)

13a. First dorsal with 17 spines; body outside corselet uniformly scaled; total gill rakers 73 to 75 (24-25 + 48-51); sides of body devoid of any conspicuous colour pattern.

Allothunnus fallai Serventy

13b. First dorsal with 15 spines; body outside corselet naked; total gill rakers not exceeding 60; body with conspicuous colour pattern 14

14a. Four to six dark conspicuous longitudinal stripes on lower half of body; gill rakers 15 or 17 + 33 to 42.

Katsuwonus pelamis (Linnaeus)

14b. No dark stripes on lower half of body, instead a few conspicuous black spots on side of body behind corselet below pectoral base; gill rakers 7 to 10 + 22 to 25.

Euthynnus affinis affinis (Cantor)

3 DOUBLE-LINED MACKEREL Grammatorcynus bicarinatus (Quoy and Gaimard, 1824)

3.1 Synonyms

Thynnus bicarinatus Quoy and Gaimard, 1824
Thynnus bilineatus Rüppell, 1835
Grammatorcynus bilineatus Gill, 1862
Nesogrammus piersoni Evermann and Seale, 1907
Grammatorcynus bicarinatus McCulloch 1922
Grammatorcynus bicarinatus (in part) Fraser-Brunner 1950)

3.2 References from Indian Ocean and contiguous waters

Quoy and Gaimard (1824); Rüppell (1835); Günther (1860); Kluzinger (1871); Hardenberg (1935); Fraser-Brunner (1950); de Beaufort (1951); Roux-Estevi and Fourmanoir (1955); Munro (1958b); Jones, Silas and Dawson (1960); Jones and Silas (1960, 1962a); Silas (1962e).

3.3 Distribution

General: Red Sea, eastwards to coast of Australia; New Guinea; Marshall Islands; Sulu Sea; Philippines; and Ryukyu Islands, Japan.

In Indian Ocean and contiguous waters: Red Sea, Andamans, west coast of Java, and west coast of Australia.

3.4 Remarks

This is a very distinct species and phylogenetically placed close to the Scombridae. Essentially a reef dweller, the species is taken on handlines along with the dogtooth tuna Gymnosarda unicolor, the rainbow runner Elagatis bipinnulatus, the dolphin, Coryphaena hippurus and similar fishes from the vicinity of reefs.

References to work dealing with this species outside the Indian Ocean are mainly those by Kishinouye (1915. 1923); Evermann and Seale (1907); McCulloch (1922); Herre (1953); Roxas and Martin (1937); Umali (1950); Warfel (1950); Wade (1951); Sette (1952); Dung and Royce (1953); Ogibly and Marshall (1954); Munro (1958a) and Schultz (1960).

The synopsis of biological data on this species presented at this conference by Silas (1962e) summarises available information.

4 FRIGATE MACKERELS Genus Auxis Cuvier

Two forms of frigate mackerels, a short corseletted and a long corseletted one are at present recognised from the Indo-Pacific and denoted as Auxis thazard (Lacépède) and A. thynnoides Bleeker respectively. The Atlantic and Mediterranean frigate mackerel appears to be the short corseletted form for which the name A. thazard has been used, although detailed comparison between the typical A. thazard from the Sunda Sea (from where the species was first described) and those from the Atlantic is wanting. It is also of special interest that whilst the two forms mentioned above are recognisable throughout the Indo-Pacific distributional range of the genus, only one type should be known from the Atlantic and Mediterranean. Matsumoto (1959) however suggests the likelihood of the occurrence of the long corseletted form in the Atlantic as well, but this needs elucidation.

Intermediate conditions in the nature of the corselet (Jones and Silas, 1962a) may give rise to some doubts as to the identity of the two species. If so, the gill-raker counts as well as the following characters not mentioned in the 'key' but dealt with elsewhere (Jones and Silas, 1962a) should facilitate identification:

1. For A. thazard the gill rakers number 9-10 and 29-32 in the upper and lower limbs of the outer arch giving a total of 39-42 while in A. thynnoides they are 8-12; 31-36 and 40-47 respectively.

2. The forward extension of the scaleless portion of the body above the lateral line was found to differ in the two species. As could be seen from figure 1a, in A. thynnoides a vertical line drawn through the anterior end of the scaleless area passes downwards not touching the tip of the pectoral fin, while in A. thazard (Figure 1b, c) the line passes through the posterior third

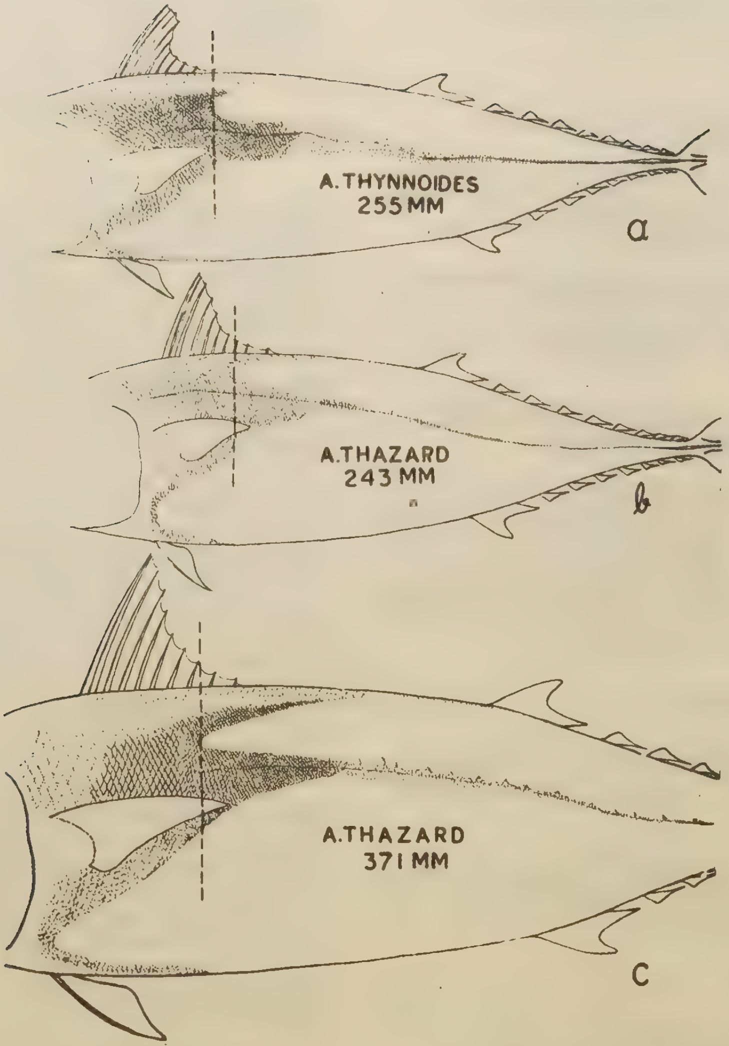

A.THYNNOIDES
255 MM
a
A.THAZARD
243 MM
b
A.THAZARD
371 MM
c

Figure 1. Forward extent of scaleless portion above lateral line in relation to pectoral fin in specimens of *Auxis thazard* and *A. thynnoides* (after Jones and Silas, 1962)

or fourth of the fin.

3. The viscera *in situ* in specimens of about the same length in both the species shows differences in the disposition of the organs (Figure 2). In *A. thazard* (Figure 2a, c) when viewed ventrally, the right lobe of the liver takes a complete loop crossing over the mid-ventral longitudinal axis while in *A. thynnoides* the right lobe does not show such a curve and even the hepatic vein does not fall in line with the mid-ventral longitudinal axis. In the former, the stomach (whether containing food or empty) extends to slightly behind the level of the anal opening as the right lobe of the liver, while in *A. thynnoides* the stomach is shorter, the distal end hardly reaching the vent, though the right lobe of the liver may extend slightly backwards, but apparently not surpassing a line above origin of anal fin. The caecal mass in *A. thynnoides* is more developed and occupies a greater space than in *A. thazard* in which species the spleen is smaller. The left lobe of the liver in *A. thazard* is relatively longer than in *A. thynnoides*. In a lateral view, part of the gall-bladder can be seen in the latter species (Figure 2d) while it is not so in *A. thazard*.

4. In general body form, *A. thynnoides* is more rounded and robust while in *A. thazard* the body is more compressed from side to side. (Figure 3) Six cross sections (A-F) taken at almost identical locations of the body in a specimen each of *A. thazard* (243 mm) and *A. thynnoides* (255 mm) illustrate further differences between the two species. The shape of the visceral cavity is totally different in the two species. Besides, in *A. thazard* (Figure 3 b, c, d) it appears to be slightly asymmetrical probably due to the looping of the liver ventrally, and accommodation in the form of narrow cavities for the liver and stomach above the origin of the anal fin is seen (Figure 3 e). There appear to be slight differences in the disposition of the coloured portion of the muscles in both the species. As the specimens are formalin-preserved however, over a period of time, many details are not discernible. Sections at the origin of the second dorsal (Figure 3 d) in both the species show that in *A. thynnoides* the number of myotomes cut through is more than for *A. thazard*.

Godsil (1954) has drawn attention to certain other anatomical differences between the long corseletted and short corseletted forms. Godsil (1954) and Matsumoto (1959) comment that the gill raker counts for *A. thazard* from the eastern Pacific are higher than for specimens from the central and western Pacific, very closely approximating the condition seen in *A. thynnoides*. This would need further investigation as Wade (1949) described two specimens from the Pacific coast of Central America (Schaefer and Marr, 1948 collection) showing higher gill raker counts as *A. thynnoides*. The close similarity between the two species may be responsible for several discrepancies in species identity in earlier literature and there is a great need for a more detailed comparison between these two species as well as in the same species, on a global basis.

5 SHORT CORSELETTED FRIGATE MACKEREL (*Auxis thazard* Lacépède, 1801)

5.1 *Synonyms*

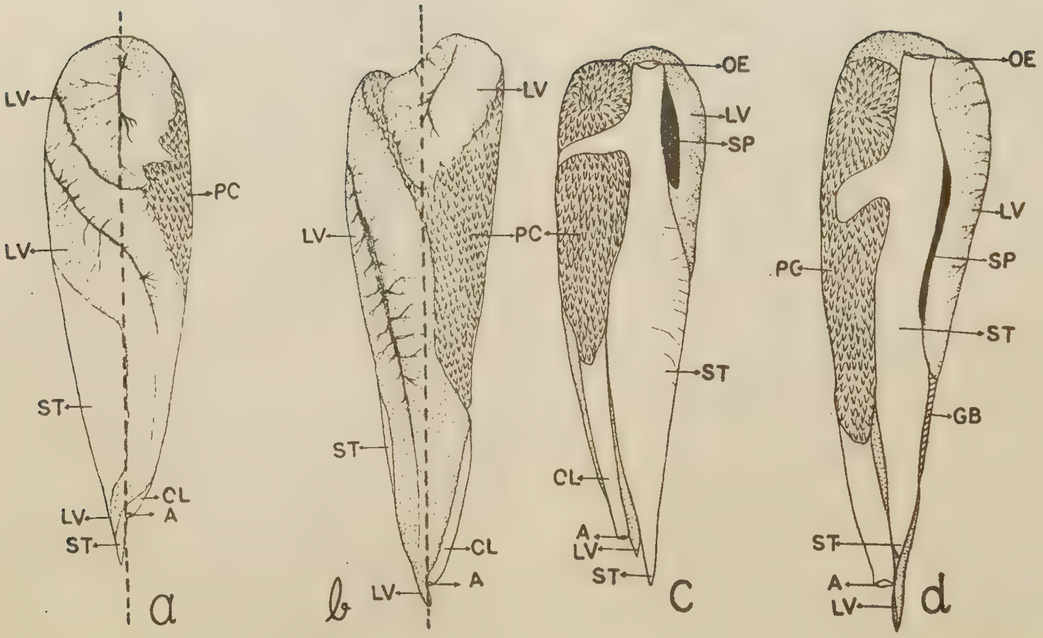
Scomber thazard Lacépède, 1801
Scomber bisus Rafinesque, 1810
Scomber rochei Risso, 1810
Thynnus rocheanus Risso, 1826
Auxis vulgaris Cuvier, 1831
Auxis taso Cuvier, 1831
Auxis tapeinosoma Bleeker, 1854
Auxis rochei (partim) Günther, 1860
Auxis thazard Jordan and Evermann, 1896
Auxis hira Kishinouye, 1915
Auxis thazard (partim) Fraser-Brunner, 1950

5.2 *References from Indian Ocean and contiguous waters*

Günther (1860); Fowler (1928); Jones (1958, 1962); Williams (1960, 1962); Jones and Silas (1960, 1962a); Ranade (1961); Silas (1962b); Talbot (1962); Whitley (1962); Jonklass (1962);

5.3 *Distribution*

General: Atlantic, Mediterranean Indo-Pacific.


LV
PC
LV
ST
CL
LV
A
ST
a
LV
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b
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ST
CL
A
LV
ST
c
OE
LV
SP
PC
ST
GB
ST
A
LV
d

Figure 2. Ventral and lateral views of viscera *in situ* in: (a and c) *Auxis thazard* and (b and d) *A. thynnoides* 243 mm and 255 mm in length respectively. (A - Anal opening; CL - Colon; GB - Gall bladder; LV - Liver; OE - Oesophageal end; PC - Caecal mass; SP - Spleen; and ST - Stomach) (after Jones and Silas, 1962)

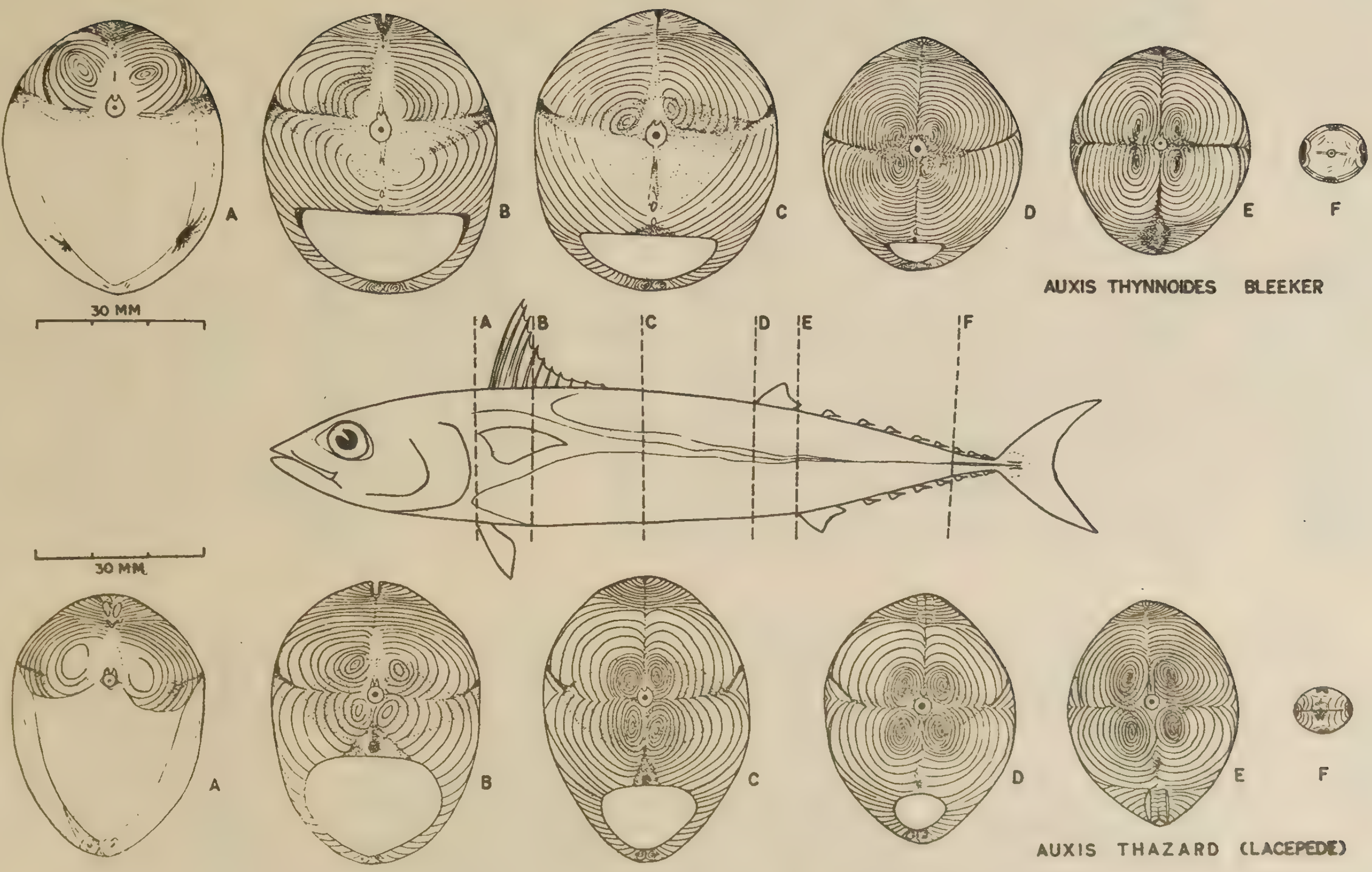
A
B
C
D
E
F
AUXIS THYNNOIDES BLEEKER
30 MM
A
B
C
D
E
F
30 MM
A
B
C
D
E
F
AUXIS THAZARD (LACEPEDE)

Figure 3. Schematic drawing of *Auxis* showing locations from where 6 cross sections of the body (A-F) were made of *Auxis thynnoides* and *A. thazard*, illustrated alongside showing differences in body shape and shape of abdominal cavity (after Jones and Silas, 1962)

In Indian Ocean and contiguous waters: East coast of South Africa from Natal coast northwards; Gulf of Aden; west and east coasts of India; Laccadives, Maldives; Ceylon, south west Sunda Sea; Western Australia.

5.4 Remarks

A seasonal visitor to the coastal waters, *A. thazard* is usually caught in shore seines, drift nets and by trolling. It is the more common of the two species of the genus and collections have been examined by the authors from various parts along the west coast of India from Veraval (Gujurat) to Cape Comorin; from the east coast from Tuticorin and from the Laccadive Sea, but no appreciable differences have been noticed.

It may be mentioned here that de Beaufort's (1951) description given under *A. thazard* actually refers to the next species. A question which may be difficult to settle is whether Lacépède's *A. thazard* from New Guinea actually refers to the short corseletted form as currently believed.

6 LONG CORSELETTED FRIGATE MACKEREL (*Auxis thynnoides* Bleeker, 1855)

6.1 Synonyms

Auxis thynnoides Bleeker, 1855
Auxis thazard (nec Lecépède, 1935)
  Jordan and Evermann 1900;
  de Beaufort, 1951
Auxis thazard (partim) Fraser-Brunner, 1950
Auxis rochei (partim) Günther, 1860
Auxis maru Kishinouye, 1915
Auxis tapeinosoma (nec Bleeker)
  Herre and Herald, 1951;
  Jones 1958, 1960;
  Talbot, 1962
  of Japanese workers.

6.2 References from Indian Ocean and contiguous waters

Bleeker (1855); Fraser-Brunner (1950); Rosa (1950); de Beaufort (1951); Jones (1958, 1962 a, b); Williams (1960); Jones and Silas (1960, 1962 a); Kumaran (1962); Talbot (1962).

6.3 Distribution

General: Indo-Pacific.

In Indian Ocean and contiguous waters: East coast of South Africa off Cape Peninsula and Mosal Bay; west coast of India (Malpe, Calicut, Quilandy, Vizingam and Colachel).

6.4 Remarks

For long a problematic species, its position in the system is now well defined. Jones (1962) has summarised the knowledge on this species from which it would appear that much more has been written about it than one would expect. Talbot (1962) who records this along the east coast of South Africa mentions "said to attain about 600 mm. South African specimens known to 300 mm". We have measured specimens up to about 300 mm from the west coast of India, but much larger specimens have, on at least one occasion, been noticed in the curing yard at Vizhingam on the south-west coast of India.

Unlike *A. thazard* this species is rarely seen in commercial catches, but when it occurs it is seen in very large shoals and considerable quantities are landed by shore seine.

7 LEAPING BONITO (*Cybiosarda elegans* Whitley, 1935)

7.1 Synonyms

Cybiosarda elegans Whitley, 1935
Gymnosarda elegans Fraser-Brunner, 1950

7.2 References from Indian Ocean and contiguous waters

Whitley (1935, 1962); Serventy (1941); Fraser-Brunner (1950); Munro (1958); Jones and Silas (1960, 1962a).

7.3 Distribution

General: East and west coast of Australia.

In Indian Ocean and contiguous waters: Along west coast of Australia at least as far south as Fremantle.

7.4 Remarks

The authors feel that Cybiosarda elegans should be retained as a distinct genus and species, although Fraser-Brunner (1950) relegated the genus to the synonym of Gymnosarda. The presence of villiform teeth in the vomer, the greater number of dorsal and anal finlets (9 or 10/7 or 8) and 15 or 16 dorsal spines in Cybiosarda should differentiate it generically from Gymnosarda in which genus the vomer is edentulous, the dorsal and anal finlets fewer (6 or 7/6 or 7), and the dorsal spines number 12 to 14.

By its occurrence along the west coast of Australia, it qualifies to be included in this account. Information on the biology of this tuna is scarce, but indications are that like Allothunnus, and Thunnus (T. alalunga, etc.), it is subtropical in distribution. According to Serventy (1941) it is said to be an excellent sport fish and specimens between 3/4 lb and 2 lb are usually taken in trolling, and shoals of many hundreds are often seen. Serventy further remarks that "..... is the one tuna whose flesh is appetizing in the fresh condition. The meat is white and may be smoked quite well".

8 ORIENTAL BONITO (Sarda orientalis Temminck and Schlegel), 1842

8.1 Synonyms

Pelamys orientalis Temminck and Schlegel, 1842
Pelamys chilensis Day, 1878, 1889 (nec Cuvier)
Sarda velox Meek and Hildebrand, 1923
Sarda orientalis Kishinouye, 1923
Sarda chilensis (partim) Bernard 1927
Sarda orientalis serventyi Whitley 1945
Sarda chilensis Smith, 1948 (nec Cuvier)

8.2 References from Indian Ocean and contiguous waters

Günther, (1860); Day, (1878, 1889); Barnard (1927); Chabanaud, (1944); Whitley (1945, 1962); Smith (1948, 1961); Wheeler and Ommanney (1953); Fraser-Brunner, (1950); Jones (1960); Jones and Silas (1960, 1962a); Rosa and Laevastu (1961); Rao (1962); Talbot (1962); Silas (1962a, 1962d).

8.3 Distribution

General: Indo-Pacific.

In Indian Ocean and contiguous waters: Natal coast of South Africa; Somalia coast; Gulf of Aden; south west coast of India; Seychelles; south west coast of Australia.

8.4 Remarks

The synopsis of biological data on the oriental bonito from the Indian Ocean (Silas 1962b) summarises existing knowledge about the species from this area. Godsil (1955) has shown that S. velox and S. orientalis are conspecific. The known distributional pattern of the species shows that while only two species, S. orientalis and S. chilensis are recognisable from the Indo-Pacific (latter only in the Pacific) the distribution of S. orientalis is not continuous, but appears to be isolated to certain coastal stretches, and the species has not been collected from the high seas of the Indian Ocean. It is evidently this disjunct distribution that led Whitley (1945) to designate the southwestern Australian population as a subspecies S. orientalis serventyi. Along the east coast of Africa also, the species which occurs along the Natal coast and upward has not been collected from the British East African coast, but is known from further north from the Somali coast where there appears to be a minor fishery for it. It is found in the Seychelles plateau and also along the west coast of India where it forms a seasonal fishery along the Kerala coast. Comparison of good series of specimens from these areas with material of the typical S. orientalis from Japanese waters is wanting.

Kumaran (1962) has studied the food of juvenile S. orientalis from Kerala coast while Silas (1962 a, d) and Rao (1962) have made observations on the fecundity and spawning habits of this species in Indian waters.

9 DOGTOOTH TUNA (Gymnosarda unicolor Rüppell)

9.1 Synonyms

Thynnus unicolor Rüppell, 1838
Pelamys nuda Günther, 1860

Gymnosarda nuda Kishinouye, 1915
Scomber vau Curtiss, 1938
Gymnosarda unicolor Fowler 1949

9.2 References from Indian Ocean and contiguous waters

Rüppell (1838); Günther (1860); Kluzinger (1871); Kishinouye (1923); Rosa (1950); Fraser-Brunner (1950); Wheeler and Ommanney (1953); Williams (1956, 1962); Smith (1956); Fourmanoir (1957, 1962); Migdalski (1958); Blanc and Postel (1958); Whitley (1962); Jones, Silas and Dawson (1960); Jones and Silas (1960, 1962a); Silas (1962c).

9.3 Distribution

General: Red Sea to Tahiti in the South Pacific and northwards to Ryukyu Islands, Japan.

In Indian Ocean and contiguous waters: Red Sea; British East African coast; Madagascar; Seychelles; Mauritius; Reunion; Maldives; Laccadives; Basses Reef along south east coast of Ceylon; Andamans; Indonesian waters south of Java.

9.4 Remarks

As is the case of the double-lined mackerel *Grammatorcynus bicarinatus* and the wahoo *Acanthocybium solandri*, it is essentially a reef dweller.

There is hardly any doubt that the genus is monotypic and the available data (Silas 1962c) do not indicate any marked variations in this species.

Information on the biology of this species is scarce. Specimens in mature running stage (V) have been taken from East African waters between December and February, suggesting spawning in the northeast monsoon. Specimens taken off Mafia, range from 40 lb to just under 100 lb. (Williams 1962) From the Seychelles - Mauritius area Wheeler and Ommanney (1956) reported catching on troll lines specimens 78 cm to 115 cm, weighing 12 lb to 38 lb. According to Kishinouye (1923) this species grows to about 240 cm and attains a weight of about 80 kg. (176 lb) Dung and Royce (1953) have given morphometric data for 123 specimens of *G. unicolor* from the Pacific.

10 ORIENTAL BLUEFIN (*Thunnus (T.) thynnus orientalis* Temminck and Schlegel, 1844)

10.1 Synonyms

Thynnus orientalis Temminck and Schlegel 1844
Thynnus maccoyii Castelnau, 1872
Orcynus schlegelii Steindachner 1884
Thunnus thynnus (in part) Jordan and Evermann 1896
Orcynus thynnus Kitahara, 1897
Thunnus schlegelii Jordan and Snyder, 1901
Thunnus orientalis Kishinouye, 1915, 1923
Thunnus saliens Jordan and Evermann, 1926
Thunnus phillipsi Jordan and Evermann, 1926
Thunnus maccoyii Jordan and Evermann, 1926
Thunnus thynnus maccoyii Serventy 1956
Thunnus thynnus orientalis Jones and Silas, 1960
Thinnus maccoyii Whitley, 1962
Thunnus (Thunnus) thynnus orientalis Jones and Silas, 1962

10.2 References from Indian Ocean and contiguous waters

Barnard, 1925; Serventy,(1941); Godsil and Holmberg,(1950); Nakamura et al (1951); Abe (1955); Serventy (1956); Mimura (1958); Mimura and Nakamura (1959); Smith (1961); Mimura (1961); and Talbot (1962).

10.3 Distribution

General: Indo-Pacific.

In Indian Ocean and contiguous waters: Southwestern Indian Ocean from off coast of South Africa; eastern Indian Ocean south of Java and off Western Australia.

10.4 Remarks

The nomenclature and status of bluefins from various parts of the world are in a state of chaos. *Thunnus thynnus* is recognised as the typical species from the eastern Atlantic and Mediterranean while some recognise the western Atlantic bluefin as *T. secundodorsalis*. At least three specific or subspecific names are currently in use in fishery literature to denote the bluefins from the Pacific and part of the eastern Indian Ocean, namely - T. orientalis (Japan) T. saliens (California) and T. maccoyii (around Australia and New Zealand). No attempts have been made to check the status of the bluefin, from the Indian Ocean. Jones and Silas (1960) considered it best to denote the bluefin from the Indian Ocean also as T. thynnus orientalis and would still advocate this course for the very reason that no direct comparisons of either T. maccoyii or T. saliens have been made with good series of T. orientalis from Japanese waters. The general body form, profile, short pectorals, etc. are very characteristic for bluefins while some differences in gill raker counts and a few body proportions have been noted by Godsil and Holmberg (1950), Serventy (1956) and Mather (1959) between bluefins from the Atlantic, Pacific coast of California and Australia. It is not certain however that this data would suffice to denote these as different species. For gill rakers, a range from 22 to 31 for the outer curve has been recorded by various authors from South African waters through the Indo-Pacific to the Atlantic. Serventy (1956) recognised six subspecies of bluefins from the world, mainly based on the modes of gill raker counts for the different areas:

> "Thunnus thynnus thynnus (L.)
> 1758 - European seas
> T. t. corretta (C. and V.)
> 1831 - North America, Atlantic
> coast
> T. t. saliens Jordan and Evermann
> 1926 - North America, Pacific coast
> T. t. orientalis (Temminck and
> Schlegel), 1842 - Asiatic coast of
> north Pacific
> T. t. maccoyii (Castelnau), 1872 -
> Australia and New Zealand
>
> The South African population has remained unnamed, but, from a consideration of the morphological differentiation which has gone on in similar isolated populations (vide in particular the work of Godsil and Holmberg) it will probably require designation as a new subspecies when its characters have been worked out".

Smith (1961) gives the meristic counts of T. thynnus from Cape waters as "D XII - XV 12-14+8-10. A I-III 11-12+7-9, 26-31 slender gill-rakers". The modal figures for gill rakers for different areas given by Serventy (1956) are:

"Australia: 11/22-23 = 33-34
California: 12/23-24 = 35-36
Japan: 12-13/24-26 = 36-39
Europe: 13/24-26 = 37-39".

For South African waters, Talbot (1962) gives the gill raker counts for 13 specimens of T. t. orientalis as ranging from 31 to 36 with the mode at 33-34 and for two specimens of T. t. thynnus the total counts to be 41 and 43.

Mather's (1959) data would suggest the following to be modes for bluefins from the eastern and western Atlantic:

Eastern Atlantic: 12/25-27 = 37-39
Western Atlantic: 13/25-27 = 38-40

The Japanese call the bluefin from the eastern Indian Ocean indomaguro (T. maccoyii of Australia) and large-scale fishing for it is carried out at two centres, one 10° to 17°S and 113° to 120°E and the second 20° to 30°S and 100° to 110°E. Mimura (1961) suspects that although the fish in both these areas may belong to the same population, two spawning groups may exist as seen from differences in length/weight and gonad weight of specimens caught from these areas.

While evidences at present tend to picture the bluefins as six isolated populations, it may be mentioned that unlike the yellowfins the bluefins may occur in waters with a temperature as low as 12°C. Our knowledge is too inadequate to even speculate whether there could be mixing between bluefins from the eastern Atlantic and South Africa (Cape Sea) and between the latter and those in the Indian Ocean except for observations made by Talbot (1962). So also little is known about the movements of the bluefin in the Pacific though it is at present presumed to be localised (Chatwin and Orange, 1960). The taxonomic distinctions are very subtle and it is the authors' contention that until good series from all these areas as well as from the Indian Ocean are critically examined, it will be better to use the oldest name available for the bluefins from the Indo-Pacific, namely, *T. orientalis*, and on account of the considerable similarities between the bluefin of the Indo-Pacific and the Atlantic to consider it a subspecies of *T. thynnus* from the Atlantic.

11 ALBACORE (*Thunnus* (*Thunnus*) *alalunga* Bonnaterre, 1788)

11.1 Synonyms

Scomber alalunga Bonnaterre, 1788
Scomber alalunga Gmelin, 1789
Scomber germo Lacépède, 1800
Orcynus germon Cuvier, 1819
Orcynus alalonga Risso, 1826
Thynnus alalonga Cuvier, 1831
Thynnus pacificus Cuvier, 1831
Thunnus alalonga South, 1845
Germo alalunga Jordan and Evermann, 1896
Germo germo Jordan and Seale, 1906
Thunnus alalunga Jordan, Tanaka and Snyder, 1913
Thunnus germo Kishinouye, 1923
Germo alalonga Barnard, 1927

11.2 References from Indian Ocean and contiguous waters

Ueyanagi (1955); Suda (1956); Mimura (1957); Yabe *et al* (1958); Kurogane and Hiyama (1959); Jones and Silas (1960, 1962a); Hiyame and Kurogane (1961); Baissac (1962); Talbot (1962); Whitley (1962); Williams (1962).

11.3 Distribution

General: Atlantic, Indo-Pacific and contiguous seas; see under 'Remarks'.

11.4 Remarks

There are no definite records of this species from the Indian coast. Apparently it is a southern species found more towards the southern latitudes, just south of the equator.

However, Japanese tuna long-line fishery data (Anon, 1959) indicate that during certain months (March, April and May) albacore may occur in catches a few degrees north of the equator also. Throughout the year, the albacore was found to occur in appreciable abundance between latitudes 1°N and 12° to 15°S and from 52°E to 120°E. Even within this area, the seas southwest of Sumatra and south of Java were found to yield the maximum catch of albacore, in one sector the maximum rate of catch being over 11 per 100 hooks used.

No attempts have been made to study albacore populations in the Indian Ocean. Some workers have treated the Atlantic albacore as *alalunga* and the Pacific as *germo*, but hitherto no detailed comparisons have been instituted and even so it is highly doubtful from available data whether more than one species of albacore exist.

Hiyama and Kurogane (1961) opine that in the Indian Ocean south of Sunda Islands the albacore belong to the same population as the ones from the equatorial areas of the Indian Ocean. They find marked differences between albacore from the Indian Ocean and from the Pacific in head length and relative positions of fins. Also the relative growth rate of the Indian albacore is more than that of the Pacific. The Indian albacore differs from those of the northwest Pacific in having larger head and more posteriorly positioned fins and these differences along with their disjunct distribution have led them to consider albacore from both these areas as belonging to two distinct populations. Since samples from the Indian Ocean and southwest Pacific show greater agreement in morphometric characters they suspect that albacore from these two areas may be the same with possibilities of regular mixing.

Mimura (1957) draws attention to the two fishing grounds for albacore in the Indian Ocean, one along the equator (April-September) and the second south of 8°S (January-March). From the southern waters of Sunda Islands (Indian Ocean) Ueyanagi (1955) obtained two albacores, one with ripe ovaries and the second with nearly ripe ones from an examination of which he deduces that the spawning of albacore takes place in that area "in February at least in part". Yabe *et al* (1958) report the occurrence of a juvenile albacore 258 mm (vertebral length) from the stomach of a female shortnosed spearfish 130 cm long collected on 20.3.1957 at 25°13'S and 99°43'E. Suzuki *et al* (1958) give data for 20 specimens of albacore collected from the eastern Indian Ocean for investigations on the blood groups of albacore. Shimadu and Higasa (1960) have studied the riboflavins in the liver and kidney of albacore from the eastern Indian Ocean. Watanabe (1960) has given data regarding the composition of food in 21 specimens of albacore from the eastern Indian Ocean. For experimental fishing for albacore and other tuna reference should be made to Kataoka (1957).

The optimum temperature for albacore is 18°C - 21°C while the species may be present in water 10°C - 28°C. Williams (1962) records the albacore for the first time from East African waters, his material consisting of a single female, ripe running to partly spent (VI-VII) measuring 1065 mm caught by longline off Mafia Island in July 1959.

12 BIGEYE TUNA (*Thunnus (Parathunnus) obesus sibi* Temminck and Schlegel 1844)

12.1 Synonyms

Thynnus sibi Temminck and Schlegel 1844
Orcynus sibi Kitahara, 1897
Thunnus sibi Jordan and Snyder, 1901
Germo germo (nec Lacépède) Jordan and Evermann, 1905
Thunnus mebachi Kishinouye, 1915
Parathunnus mebachi Kishinouye, 1923
Parathunnus sibi Jordan and Hubbs 1925
Parathunnus obesus mebachi Jones and Silas, 1960
Thunnus obesus (partim) Collette, 1961

12.2 References from Indian Ocean and contiguous waters

de Beaufort (1951); Maeda (1955); Kataoka (1957); Mimura, (1957); Yabe, Ueyanagi, Kikawa and Watanabe, (1958); Fujii and Higasa, (1959); Fujii, Mimota and Higasa, (1959); Nakagome, (1959b); Jones and Silas, (1960, 1962a); Suzuki and Morio (1960); Watanabe, (1960); Hiyama and Kurogane, (1961); Talbot, (1962).

12.3 Distribution

General: Indo-Pacific

12.4 Remarks

The authors agree with Fraser-Brunner (1950); Rivas (1961); Collette (1961) and others that only one species of bigeye tuna may be recognised from the Atlantic and the Indo-Pacific. Although the specific names *sibi* and *mebachi* have been applied to the Pacific bigeye tuna and Jones and Silas (1960) have used the name *mebachi*, the authors tentatively recognise *sibi* (the oldest name) as representing the Indo-Pacific subspecies of *T. (P.) obesus*. Comparison of samples from the Indian Ocean with those from the Atlantic is wanting. A specimen of bigeye examined by Jones and Silas (1960) shows characters more akin to the Atlantic *T. obesus* than to *P. mebachi* figured by Godsil and Byers (1944). The latter appears to have a markedly longer pectoral. Roedel and Fitch (1961) have drawn attention to the desirability of making a comparative examination of the livers of the bigeye tunas from the Atlantic and the Pacific since the description of the nature of the striations on the liver given by Mather (1959) and Godsil and Byers (1944) indicates likely differences.

Hiyama and Kurogane (1961) found that morphometrical comparison of bigeye tuna from the Indo-Pacific based on samples taken from various fishing grounds did not lead to any conclusive results since the samples were inadequate. However, certain trends are indicative, such as, "Among the bigeye tuna from the equatorial area of the Indian Ocean, as well as the yellowfin tuna, the eastern fish differ from the western fish in having larger heads and more posteriorly positioned fins. The fish from the waters south of the lesser Sundas differ greatly from those from the equatorial area. The former have a shorter head and more anteriorly positioned fins than the latter. The differences between the fish from the area south of the lesser Sundas and from the Banda Sea and the Palao area are not so great as we saw between the former and equatorial Indian Ocean ones".

For biochemical studies on bigeye tuna based on material from Indian Ocean reference may be made to Fujii and Higasa (1959) and Fujii, Mimoto and Higasa (1959).

Serological studies have been attempted by Suzuki and Morio (1960), while Mimura (1957), Kataoka (1957), Nakagome (1959b) and others have given data on bigeye tuna from parts of the Indian Ocean dealing with length frequencies; annual and periodic variations in fishing conditions etc.

13 NORTHERN BLUEFIN (Kishinoella tonggol Bleeker 1851)

13.1 Synonyms

?Thynnus argentivittatus Cuvier, 1831
(lectotype as selected by Schaefer and Walford, 1950: type locality; Malabar Coast, India)
Thynnus tonggol Bleeker, 1851
Neothunnus rarus Kishinouye, 1923
Deraniyagala, 1933
Kishinoella rara Jordan and Hubbs, 1925
Neothunnus tonggol Jordan and Evermann, 1926
Thunnus maccoyi (partim) McCulloch, 1929
Thunnus rarus Delsman and Hardenberg, 1934
Thunnus nicholsoni Whitley, 1936
Thunnus tonggol Tortonese, 1939
Kishinoella tonggol Serventy, 1942
Thunnus (Kishinoella) tonggol Fraser-Brunner, 1950
?Thunnus argentivittatus Rivas, 1961

13.2 References from Indian Ocean and contiguous waters

Günther (1860); Deraniyagala (1933, 1952); Tortonese (1939); Delsman and Hardenberg (1934); Serventy (1941, 1956); Whitley (1947, 1962); Fraser-Brunner (1950); Rosa (1950); de Beaufort (1951); Munro (1955); Jones, Silas and Dawson (1960); Jones and Silas (1960, 1962a); Ranade (1961); Rosa and Laevastu (1961); Rao (1962); Silas (1962b); Jones (1962).

13.3 Distribution

General: Indian Ocean, central and western Pacific.

In Indian Ocean and contiguous waters: Somalia coast, Gulf of Aden, Karachi coast (of Pakistan), west coast of India from Kutch to Cape Comorin, Gulf of Mannar and southeast coast of India, Ceylon, Laccadives, Maldives, Andamans, Malay coast, Singapore, Sunda Archipelago and west coast of Australia.

13.4 Remarks

The history of Thunnus argentivittatus has been ably summarised by Rivas (1961) who following the suggestion put forward by Schaefer and Walford (1950) recognises it as the Indian yellowfin tuna. The authors have given elsewhere reasons for considering Cuvier's T. argentivittatus, the lectotype of which was designated by Schaefer and Walford (1950) and examined and reported on by Rivas (1961) as probably more akin to Kishinoella tonggol than to the yellowfin. Briefly stated, the reasons are: (1) K. tonggol is quite common along the Malabar coast during certain seasons when it is caught in appreciable numbers in drift net and hook and line while the yellowfin is only rarely caught in coastal waters; (2) the gill raker count of the lectotype, namely, 8 + 18 = 26, falls well within the range for K. tonggol from Indian waters as shall presently be shown, but the number is too low for the yellowfin which has a total count of about 29-32 rakers. (3) Rivas (1961) has given additional gill raker counts for three specimens (topotypes) of T. argentivittatus from the Karachi coast as 6 + 17 = 23. Here again the gill raker counts are too low for a yellowfin. Actual examination of the lectotype may further aid in confirming our viewpoint and as mentioned by the authors the specific name T. argentivittatus may have priority over T. tonggol. If so it is desirable to supress the lesser known name T. argentivittatus. Some authors (Rosa, 1950; Collette, 1961) consider Kishinoella zacalles Jordan and Evermann from Hawaiian waters as a doubtful synonym or absolute synonym of K. tonggol, though the former species was described with "9 + 21 = 30"gill rakers. Serventy (1956) gives the total gill raker counts for Australian specimens of K. tonggol as 19-25 with the mode at 22 and Silas (1962b) gives the counts for K. tonggol taken on troll line in the Gulf of Mannar as 22-27 (6-8+16-19) with the mode at 7+18 = 25. These counts are much on the lower side when compared with that known for K. zacalles. Strangely enough there appears to be no records of *K. zacalles* after its original description to help solve the problem as to whether there exists such a species at all. The absence of air bladder is perhaps an important character which prompted Jordan and Evermann (1926) to place *zacalles* under the genus *Kishinoella*. However, the colour pattern for the species, as well as the gill-raker counts show much in common with the Pacific yellowfin *T. (Neothunnus) albacares macropterus*. Jones and Silas (1962a) suggest that it could be a synonym of that species or even bigeye tuna (*T. (Parathunnus) obesus sibi*) rather than of *K. tonggol*.

K. tonggol contributes to a seasonal minor fishery along the west coast of India and in the Gulf of Mannar. The synopsis of biological data on the species from the Indian Ocean (Jones, 1962) summarises the knowledge about it from this area.

14 YELLOWFIN TUNA (*Thunnus (Neothunnus) albacares macropterus* Temminck and Schlegel 1844)

14.1 Synonyms

Albacores or *Thynni* Sloane, 1707
Scomber albacares Bonnaterre, 1788
Scomber albacorus Lacépède, 1800
Scomber sloanei Cuvier, 1831
Thynnus albacora Lowe, 1839
Thynnus macropterus Temminck and Schlegel, 1844
Thynnus argentivittatus South, 1845 (nec Cuvier)
Orcynus macropterus Kitahara, 1897
Germo macropterus Jordan and Snyder, 1901
Thunnus macropterus Jordan, Tanaka and Snyder, 1913
Neothunnus macropterus Kishinouye, 1923
Thunnus albacora (partim) Fraser-Brunner, 1950
Thunnus (Neothunnus) argentivittatus Deraniyagala, 1952

14.2 References from Indian Ocean and contiguous waters

Serventy (1941); Molteno (1948); Smith (1949, 1961); de Beaufort (1951); Deraniyagala (1952); Hirano and Tagawa (1952); Wheeler and Ommanney (1953); Royce (1953, 1961); Maeda (1955); Munro (1955); Tsuruta (1955, 1961, 1962); Fourmanoir (1957); Kataoka (1957); Kurogane and Hiyama (1958); Mimura (1958, 1962); Nakagome (1958, 1962); Jones (1959); Jones and Silas (1960, 1962a); Tsuruta and Tsunoda (1960); Watanabe (1960); Yabatu, Yukinawa and Warshina (1960); Hiyama and Kurogane (1961); Baissac (1962); Fourmanoir and Crosnier (1962); Jones and Kumaran (1962); Jonklaas (1962); Silas (1962b); Silas and Ummerkutty (1962); Talbot (1962); Thomas (1962 a b Whitley (1962); Williams (1962).

14.3 Distribution

General: Tropical and temperate waters of Indo-Pacific.

In Indian Ocean and contiguous waters: East coast of South Africa from Cape Sea northwards to Somalia coast; Gulf of Aden; off west coast of India; Gulf of Mannar; Ceylon; Laccadives; Maldives; Chagos Archipelago; Seychelles - Mauritius; Madagascar; Reunion; Andamans; South Sunda Sea; off west coast of Australia and in the high seas of tropical and temperate Indian Ocean and from several other localitites.

14.4 Remarks

Over 30 references given above cover aspects of the taxonomy, biology and fishery of the yellowfin from the Indian Ocean. On the basis of morphometric studies of yellowfin from the Indo-Pacific, Royce (1961) found that ".... the yellowfin from the Pacific show a continuous cline in morphology along the Pacific equator, whereas, the samples removed from the equator differ erratically from the equatorial cline. However, the dimensions are within the range of characters in the cline or are so close to one end or other of the cline that there appears to be no evidence of genetically isolated stocks in the Pacific". Further from the Indian Ocean he found the sample from off Somaliland (northeast Africa) to be the most diverse one when compared to 23 other samples from various parts of the Indo-Pacific and one from Angola, Africa. According to him "It is similar to one or more central Pacific equatorial samples in head length, snout to insertion of first dorsal but has very short pectoral, second dorsal, and anal fins. Somaliland fish also have a very long distance from the snout to the insertion of the anal, an especially deep body, and a long distance from the snout to the insertion of the ventrals. It is very different from the sample from the other side of Africa near Angola,.....". However, the specimens having been drawn from a smaller size group and the sample itself inadequate, it is not known whether yellowfin from the northeast coast of Africa constitute a distinct population.

Tsuruta (1961) found greater similarities in morphometrical characters between yellowfin from southwest of Madagascar (southwest Indian Ocean) and Angola (southeast Atlantic).

Hiyama and Kurogane (1961) are of the opinion that there are a number of independent or semi-independent populations of yellowfin within each ocean distributed in rather localised waters, intermingling with each other, "because of the positive differences of morphometrical features between the adjoining populations". They find that the yellowfin from the equatorial area of the Indian Ocean show differences as follows ".... the eastern fish have a larger head, more posteriorly positioned ventral and pectoral fins, and longer fins than the western. The yellowfin tuna from the areas south of the lesser Sunda Islands differ from the equatorial ones in having a shorter head and more anteriorly, positioned fins. The specimens from the Lesser Sundas are rather similar to those from the vicinity of the Andaman Islands, with respect to the length of the second dorsal and anal fins. Accordingly, it is probable that the yellowfin tuna inhabiting the waters adjacent to the Lesser Sundas belong to a population distinct from that of the equatorial Indian Ocean, and that the western equatorial ones are somewhat different from the eastern equatorial ones, with some intermingling between them".

These draw attention to the need for more intensive study on populations of yellowfin tuna from the Indian Ocean as the picture is far from clear.

As regards the species, the authors feel it desirable to denote the yellowfin from the Indian Ocean also as a subspecies of *T. albacares*, namely *T. a. macropterus*, the same as the one in the Pacific.

The authors have shown earlier that *T. argentivittatus* Cuvier (1831) *et* Schaefer and Walford (1950) *et* Rivas (1961) could in fact be nothing other than *Kishinoella tonggol*. However, the specific name *argentivittatus* has at one time or another been used to denote yellowfin from this area (Deraniyagala, 1952) the Atlantic (South 1845; Rivas 1951; Beebe and Tee-Van, 1936) and the east Pacific (Nichols and Murphy, 1922).

15 *Thunnus* (*Neothunnus*?) *itosibi* Jordan and Evermann, 1926

15.1 *Synonyms*

Neothunnus itosibi Jordan and Evermann, 1926
Somathunnus guildi Fowler, 1933
Thunnus macropterus (partim) Delsman and Hardenberg, 1934; de Beaufort, 1951
Semathunnus itosibi Tinker, 1944
Neothunnus albacora (partim) Barnard, 1947
Germo itosibi Smith, 1949
Thunnus (*neothunnus*) *albacora* (partim) Fraser-Brunner, 1950
Thunnus albacores (partim) Rivas, 1961

15.2 *References from Indian Ocean and contiguous waters*

Smith (1935, 1949, 1961); Barnard (1939, 1947); Molteno (1948); Jones and Silas (1960, 1962a); Talbot (1962).

15.3 *Distribution*

General: Indo-Pacific.

Indian Ocean and contiguous waters: From coast of southeast Africa; Madras coast; Andamans; seas around Sunda Archipelago.

15.4 Remarks

The authors have not relegated this species to the synonym of the Indo-Pacific yellowfin tuna since the available data is not conclusive in showing that they are one and the same, merely representing different growth stages. Data obtained from Andaman waters indicate that specimens of "yellowfin" about 120 cm show both the elongate *itosibi* type of second dorsal and anal fins while some have short fins. More information is needed and until such time this species is given tentative recognition only.

16 SLENDER TUNNY (*Allothunnus fallai* Serventy , 1948)

16.1 Synonyms

Allothunnus fallai, Serventy, 1948

16.2 References from Indian Ocean and contiguous waters

Talbot (1962).

16.4 Remarks

First described by Serventy (1948) from Timaru, South Island, New Zealand, the species has since been reported from the south and southeast coasts of Tasmania (Whitley 1962) and from South African waters (Talbot, 1952). The known distributional range indicates it to have only a subtropic distribution, and its disjunct occurrence at present is interesting.

Nothing is known about the biology or habits of this species. Phylogenetically it would appear to be more allied to the genera *Katsuwonus* and *Euthynnus* (Serventy, 1948).

17 LITTLE TUNNY (*Euthynnus affinis affinis* Cantor, 1850)

17.1 Synonyms

Thynnus affinis Cantor, 1850
Thynnus thunnina (*nec* Cuvier) Bleeker, 1852; Day, 1878
Euthynnus alletteratus Deraniyagala, 1933 (*nec* Rafinesque) Serventy, 1941 (*nec* Rafinesque)
Euthynnus alletteratus affinis de Beaufort, 1951
Wanderer wallisi Whitley, 1962
Euthynnus affinis affinis Fraser-Brunner, 1949
Euthynnus (*Euthynnus*) *affinis* Fraser-Brunner, 1950
Euthynnus wallisi Whitley, 1962

17.2 References from Indian Ocean and contiguous waters

Cantor (1850); Bleeker (1852); Günther (1860); Day (1878, 1889); Maxwell (1921); Deraniyagala (1933, 1952); Fowler (1934); Serventy (1941); Fraser-Brunner (1949a, b, 1950); de Beaufort (1951); Wheeler and Ommanney (1953); Fourmanoir (1954, 1957, 1962); Morrow (1954); Munro (1955); Steinitz and Ben-Tuvia (1955); Smith (1956, 1960); Williams (1956, 1962); Blanc and Postel (1958); Nayar (1958); Jones *et al* (1960); Jones and Silas (1960, 1962a); Baissac (1962); Jonklaas (1962); Silas (1962b); Whitley (1962).

17.3 Distribution

General: Indian Ocean and western Pacific where it presumably merges with another subspecies *E. a. yaito*.

In Indian Ocean and contiguous waters: Widespread from entire coast of Africa, Gulf of Aden, Karachi coast of Pakistan, west and east coasts of India, Ceylon, Andaman, Burma coast; Malaya and Indonesian waters, south of Java, Western Australia and from the Laccadives, Maldives, Seychelles, Aldabra, Madagascar, Mauritius and Reunion.

17.4 Remarks

This is by far the most common tuna entering the coastal waters and forming a seasonal fishery at certain locations. (Nayar, 1958; Bennett, 1962; Ogilvie *et al* 1954; Anon, 1953). Juvenile stages have been described by Jones (1960) and distributional pattern of larvae discussed by Jones and Kumaran (1962a, b). Some observations on the food of juveniles have been made by Kumaran (1962).

It is the authors' opinion that both *E. yaito* (Kishinouye 1923) and *E. affinis* are conspecific, the differences between the two being at most of subspecific importance. There could be regular mixing between these two forms at present restricted to the central and western Pacific (yaito) and the Indian Ocean (affinis). Incidentally, Smith (1961) records E. alletteratus from Delgoa Bay to East London, southeast coast of Africa, from where E. affinis has also been caught on occasion, showing this to be an area of overlap in distribution of these two species.

18 OCEANIC SKIPJACK (Katsuwonus pelamis Linnaeus, 1758)

18.1 Synonyms

Scomber pelamis Linnaeus, 1758
Scomber pelamides Lacépède, 1803
Thynnus vagans Lesson, 1828
Thynnus pelamis Cuvier, 1831
Gymnosarda pelamys Barnard, 1925
Euthynnus pelamis Deraniyagala, 1933
Euthynnus (Katsuwonus) pelamis Fraser-Brunner, 1950
Euthynnus (Katsuwonus) pelamys Fourmanoir, 1960

18.2 References from Indian Ocean and contiguous seas

Günther (1860); Day (1878, 1899); Gilchrist (1902); Barnard (1925); Deraniyagala (1933, 1952); Serventy (1941); Molteno (1948); Fraser-Brunner (1950); Rosa (1950); Mendis (1954); Munro (1955, 1958); Fourmanoir (1957, 1960); Jones and Kumaran, (1959); Jones and Silas (1960, 1962a, b); Jonklaas (1962); Raju (1962, a, b); Smith (1961); Talbot (1962); Thomas (1962, a, b); Whitley (1962); Williams (1962).

18.3 Distribution

General: Atlantic, Mediterranean and Indo-Pacific.

In Indian Ocean and contiguous waters: Off south and east coasts of Africa; Gulf of Aden; Red Sea; Laccadives; Maldives; Gulf of Mannar; Seychelles; Mauritius; Reunion; Madagascar; seas around the Sunda Archipelago; Western Australia. Larvae have been collected in the open seas from several localities.

18.4 Remarks

The synopsis of biological data for this species from the Indian Ocean (Jones and Silas, 1962b) summarises available information about it from this area. There can be hardly any doubt that the skipjack throughout the world is referable to only a single species.

19 GENERAL CONSIDERATIONS

Existing information on the taxonomy and biology of tunas and related species from the Indian Ocean poses many problems, the elucidation of which will involve in several cases international cooperation. Recent years have seen a worldwide interest for more knowledge on tunas and other scombroid fishes resulting in the holding of three important conferences on the biology and fishery of these fishes (Dakar, Senegal, December 1960; Honolulu, Hawaii, August 1961; and Mandapam Camp, India, January 1962) culminating in the World Scientific Meeting on the Biology of Tunas and Related Species under the auspices of the Food and Agriculture Organization of the United Nations.

The Proceedings and recommendations of the earlier meetings amply draw attention to the need for more intensive studies on the systematics and biology of tunas and related fishes for a proper understanding of our potential resources. Use of new techniques such as blood typing in taxonomic studies, the proper collection of biometric data, studies on population dynamics involving assessment of fishable stocks and estimation of magnitude of the resources, and other aspects such as studies on age determination, migrations, behaviour in relation to environmental conditions etc. call for more intensive investigations. It is hoped that the present Meeting will pave the way for the initiation of such studies on a global basis.

Experience Paper No. 44

DESCRIPTION DES STADES POST-LARVAIRES ET JUVENILES DE Neothunnus albacora (Lowe) DE L'ATLANTIQUE TROPICO-ORIENTAL

par

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Résumé

Au cours de l'année 1960, treize formes post-larvaires et juvéniles attribuées à l'espèce Neothunnus albacora ont été pêchées à proximité des côtes de l'Afrique occidentale. Une quatorzième a été capturée plus récemment et vient compléter cette série.

Toutes ces captures ont été faites de nuit, en surface, à l'aide d'un projecteur et d'une épuisette à mailles fines.

On se propose dans cette étude, de donner une description des principaux stades de développement de cette espèce.

DESCRIPTION OF POST-LARVAL AND JUVENILE STAGES OF NEOTHUNNUS ALBACORA (Lowe) OF THE EASTERN TROPICAL ATLANTIC

Abstract

During 1960, 13 post-larval and juvenile forms attributed to the species Neothunnus albacora were caught off the west African coast. A 14th was caught later and now completes the series.

All the catches were made at night, at the surface, with the help of a searchlight and a fine mesh scoop net.

The paper describes the principle stages of development of the species.

DESCRIPCION DE LOS ESTADIOS POST-LARVALES Y JUVENILES DE NEOTHUNNUS ALBACORA (Lowe) DEL ATLANTICO TROPICO-ORIENTAL

Resumen

En el curso del año 1960, se han pescado en la proximidad de las costas del Africa occidental trece formas post-larvales y juveniles atribuídas a la especies Neothunnus albacora. Recientemente, se ha capturado otra que viene a completar esta serie.

Todas estas capturas se han hecho de noche, en superficie, con ayuda de un proyector y de una red de mano de malla fina.

El propósito de este estudio es dar una descripción de los principales estadios de desarrollo de esta especie.

1 INTRODUCTION

Au cours de l'année 1960, treize formes post-larvaires et juvéniles attribuées à l'espèce Neothunnus albacora ont été pêchées à proximité des côtes de l'Afrique occidentale. Une quatorzième a été capturée plus récemment et vient compléter cette série.

Toutes ces captures ont été faites de nuit, en surface, à l'aide d'un projecteur et d'une épuisette à mailles fines.

On se propose dans cette étude, de donner une description des principaux stades de développement de cette espèce.

2 DATES ET LIEUX DE CAPTURES; CONDITIONS HYDROLOGIQUES

2.1 Données

2.2 Discussion

Les dates de captures s'échelonnent de Janvier à Juillet sans que l'on puisse noter un quelconque accroissement de taille des individus pris pendant cette période.

Les lieux de captures sont situés de 10 à 100 milles marins au large des côtes de Côte d'Ivoire et du Ghana (sauf pour le plus grand pris entre l'Ile de l'Ascension et le Cap des Palmes). Certains captures ont eu lieu au-dessus de plateau continental.

La seule conclusion que l'on puisse tirer de ce paragraphe est la certitude que Neothunnus albacora se reproduit bien à proximité des côtes du Ghana et de Côte d'Ivoire.

Dates	Heure	Lieu	Distance à la côte en milles marins	Température en °C	Salinité en S‰	Taille en m/m
20.1.1960	23H.	4°32 N - 5°19 W	35	27° 81	34,26	12,93 15,06
29.3.1960	24H.	3°30 N - 3° W	93	28° 6	34,95	10,80 14,08 18,16 23,16
18.5.1960	20H.30'	3°59 N - 0°00	98	28° 9	34,52	32,9
19.5.1960	22H.	4°30 N - 1°24 W	34	28° 6	34,56	9,87 10,40 16,50 17,50
19.7.1960	22H.	5°04 N - 4°08 W	12	25°10	34,90	10,86 11,45
5.3.1962	3H	4°01 S - 12°18 W	570	27°53	35,37	53,1

3 DESCRIPTION

3.1 Spécimen de 9, 87 m/m de Lf (Longueur à la fourche caudale) (Fig. 1)

3.1.1 Morphologie

C'est le plus jeune individu que nous ayons. Il se présente avec une tête assez grande et élevée par rapport au corps. Le museau est en forme de bec, les narines sont bien séparées. Le corps se rétrécit régulièrement depuis la tête jusqu'à l'extrémité postérieure. La masse viscérale est en forme de cloche; l'anus est à mi-distance entre l'extrémité antérieure du corps et la fourche caudale.

L'armature préoperculaire se compose de trois toutes petites dents sur le bord ventral; un groupe de trois épines à l'angle dont la médiane est longue et pointue; trois petites dents sur le bord ascendant, homologues de celles du bord ventral. Une petite épine nuccale est visible au sommet de l'opercule.

On compte 13 dents sur le côté gauche de la mâchoire supérieure, 11 sur celui de la mâchoire inférieure. Ces dents sont petites mais aiguës.

La première nageoire dorsale possède 12 rayons visibles, les deux derniers étant très petits; la deuxième dorsale, 24 rayons peu formés et la nageoire anale 21. La première dorsale est très haute, formant un angle aigu avec la deuxième; son premier rayon replié atteint le début de la deuxième dorsale qui est en continuité avec la première (et dont les deux premiers rayons font en fait, vraisemblablement partie de celle-ci).

Une membrane relie la nageoire anale à l'anus.

3.1.2 Coloration

Le museau porte quelques chromatophores formant une tache à son extrémité; la mandibule également montre dans sa partie antérieure 5-6 chromatophores de chaque côté. La masse cervicale est colorée. On voit 2-3 chromatophores sur le haut de l'opercule, mais aucun autour de l'oeil.

Il y a 3 chromatophores sur le profil dorsal du 5° au 7ème rayon de la première nageoire dorsale. Aucune autre coloration n'est visible sur le corps en dehors de celle, profonde, de la cavité viscérale.

La première nageoire dorsale est vivement colorée par de gros mélanophores, plus espacés en descendant vers la base de la nageoire qui est presque incolore. Toutes les autres nageoires sont incolores.

3. 2 Spécimen de 10. 8 m/m de Lf

Ce spécimen a été coloré à l'alizarine pour permettre de dénombrer les vertèbres et de compter plus facilement les rayons des nageoires.

Vertèbres: 39, dont 18 précaudales et 21 caudales.

Armature préoperculaire: 3-1-I-1-3, ainsi que 3 petites épines en série antérieure.

Rayons de la première dorsale: 10 + 2 très petits.

Rayons de la deuxième dorsale: 2 + 22 (dont 8 pinnules).

Rayons de l'anale: 22 (dont 8 pinnules).

Demi-mâchoire supérieure: 15 dents

Demi-mâchoire inférieure : 14 dents.

Une série de 5 petites dents palatines sur chaque palatin.

3. 3 Spécimen de 12, 93 m/m de Lf (Fig. 2)

3. 3.1 Morphologie

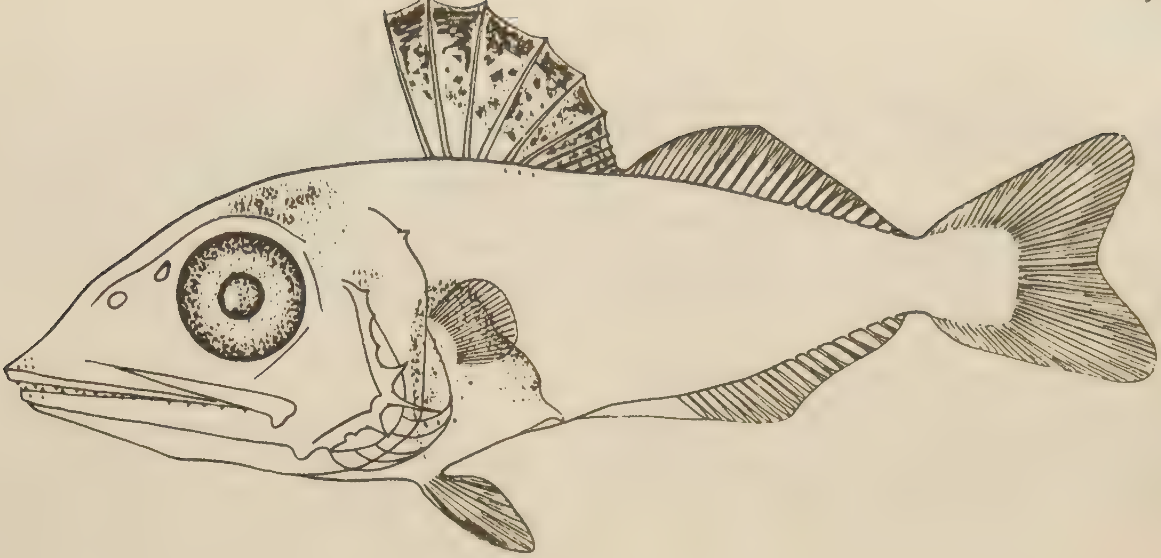

Figure 1 - Spécimen de 9, 87 m/m de Lf.
Description des stades post-larvaires et juvéniles de Neothunnus albacora (Lowe) de l'Atlantique tropico-oriental.

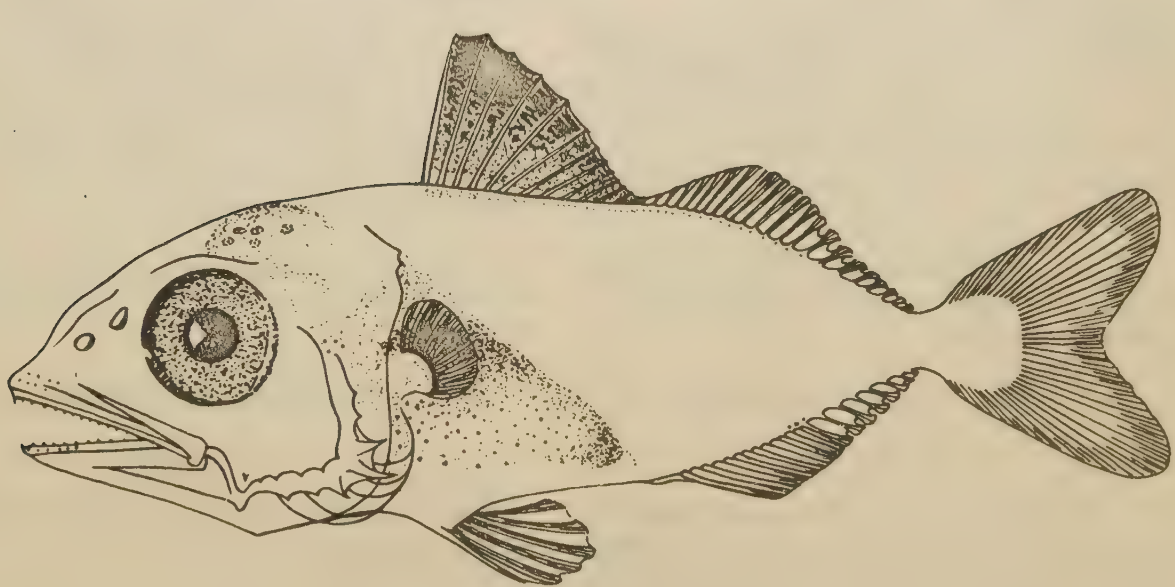

Figure 2 - Spécimen de 12, 93 m/m de Lf.
Description des stades post-larvaires et juvéniles de Neothunnus albacora (Lowe) de l'Atlantique tropico-oriental.

L'aspect du corps est encore assez semblable au premier décrit. Toutefois, le corps est plus élevé et le museau plus court.

L'armature préoperculaire présente toujours la même disposition: 3-1-I-1-2, avec l'épine médiane assez longue. On voit 2 petites épines nuccales au sommet de l'opercule.

La formule radiaire est: Dl = XIV; D2 = 21 (13 + 8); A = 22 (14 + 8). Les pinnules, bien individualisées, sont réunies entre elles par une membrane. Une petite membrane unit encore le début de la nageoire anale à l'anus.

3.3.2 Coloration

Les chromatophores du museau forment une tache s'arrêtant au niveau de la troisième dent. L'extrémité de la mandibule porte une seule rangée de chromatophores (10 environ) arrivant au niveau de la sixième dent. On voit quelques chromatophores sur le haut de l'opercule et sur le pourtour postérieur de l'orbite. La masse cervicale est également pigmentée.

Une ligne pigmentée partant du début de la première dorsale suit sa base et atteint le quinzième rayon de la deuxième dorsale. Il n'y a pas de pigmentation sur la ligne médiane. On voit un chromatophore pâle à la base des 12°, 13°, 14° rayons de l'anale. Enfin, la masse viscérale est pigmentée.

La première dorsale est d'un noir sombre sur toute sa surface, les autres nageoires, entièrement incolores.

3.4 Spécimen de 18,16 m/m de Lf (Fig. 3)

3.4.1 Morphologie

La forme du corps est assez différente du précédent. En effet, les profils dorsal et ventral (jusqu'au début de la deuxième dorsale et de l'anale) sont presque parallèles (rapport entre les hauteurs à Dl et D2 = 1,08); ensuite le corps se rétrécit rapidement.

La tête est moins grande, le museau peu marqué. On compte environ 15 dents par demi-mâchoire supérieure et inférieure. L'armature préoperculaire est encore bien visible, ainsi que les épines nuccales.

La première dorsale est assez élevée; ses rayons vont en décroissant régulièrement jusqu'au dernier (14°) qui est très petit et contigu à la deuxième dorsale, si bien que l'angle que font ces deux nageoires est en V. On compte 23 rayons à la deuxième dorsale (15 + 8) les 8 pinnules étant reliées entre elles par une membrane; il en est de même à l'anale (14 + 8).

3.4.2 Coloration

Le museau porte une tache constituée par une double rangée de 10 chromatophores atteignant le quart antérieur de la mâchoire supérieure. La mâchoire inférieure a une seule rangée de 15 chromatophores atteignant le même niveau qu'à la mâchoire supérieure. Le dessus de la tête, le bord postérieur de l'orbite et la moitié supérieure de l'opercule sont pigmentés.

A ce stade, toute la partie supérieure du corps est pigmentée, les flancs légèrement, le ventre non (sauf la masse viscérale), mais cette pigmentation s'atténue d'avant en arrière et se termine au niveau du 15ème rayon de la deuxième dorsale. Au delà, il y a encore quelques chromatophores pâles sur la ligne médiane. Le long de la base des dorsales court une ligne plus foncée qui atteint le 14ème rayon de la deuxième dorsale, suivie de 3 chromatophores séparés atteignant le 16ème rayon. La partie postéro-inférieure du corps est marquée d'un seul chromatophore à la base du 15ème rayon de l'anale.

La première dorsale est vivement colorée en noir, toutes les autres nageoires étant incolores.

3.5 Spécimen de 23,16 m/m de Lf

3.5.1 Morphologie

Peu de différence dans l'aspect général avec le précédent.

3.5.2 Coloration

Le point important est l'apparition sur le dos de quatre régions plus foncées (en avant de la première dorsale, en son milieu, entre celle-ci et la deuxième, sous le début de cette dernière) qui constituent les amorces de quatre bandes verticales.

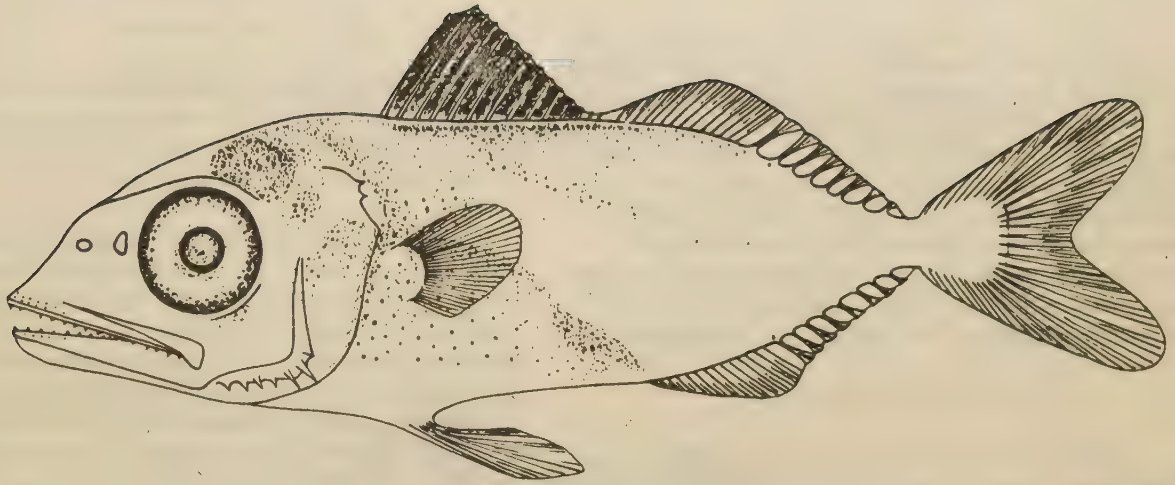

Figure 3 - Spécimen de 18,16 m/m de Lf.
Description des stades post-larvaires et juvéniles de Neothunnus albacora (Lowe) de l'Atlantique tropico-oriental.

Par ailleurs, la deuxième dorsale commence à être pigmentée dans son quart inférieur jusqu'au 12ème rayon.

3.6 Spécimen de 32,9 m/m de Lf (Fig. 4)

3.6.1 Morphologie

La tête a un museau court, avec un profil antéro-supérieur busqué au niveau de la narine antérieure. L'armature préoperculaire est englobée dans l'opercule. On distingue cependant encore les épines principales 1-I-1. Les épines nuccales ne sont plus visibles. On compte 19 branchiospines sur la partie inférieure du premier arc branchial gauche.

Le corps est assez élevé, ramassé. On distingue la partie antérieure de la ligne latérale au-dessus de la pectorale. La première dorsale qui possède 14 rayons, est haute, diminuant régulièrement vers les derniers rayons et formant un V ouvert avec la partie antérieure de la deuxième dorsale. Celle-ci est assez élevée. Les pinnules, au nombre de 8, sont bien détachées, uniquement reliées entre elles par une membrane basse. L'anale est semblable à la deuxième dorsale avec également 8 pinnules.

3.6.2 Coloration

Le museau est pigmenté en avant de la narine antérieure. La mâchoire supérieure montre une rangée de chromatophores atteignant la moitié de sa longueur, la mandibule une double rangée arrivant au même niveau. La pigmentation entoure la moitié postérieure de l'orbite et déborde sur la partie antéro-supérieure. Le préopercule, la partie supérieure de l'opercule et le dessus de la tête (sauf la région antérieure) sont pigmentés.

La partie antérodorsale du corps, jusqu'à la 5ème pinnule et légèrement en-dessous de la ligne médiane, est pigmentée. Cette pigmentation est d'ailleurs tout-à-fait caractéristique ; elle est constituée par cinq bandes verticales sombres plus foncées sur le dos et s'atténuant sur les flancs pour disparaître dans le tiers inférieur. Ces bandes sont séparés par des zones plus claires mais non entièrement dépigmentées. Le dessus du pédoncule caudal porte une plage de chromatophores, ses côtés, quelques taches, son extrémité (base des rayons de la caudale), une pigmentation formant une ligne verticale sombre. Du côté de la base de l'anale, la pigmentation des deux dernières bandes verticales se prolonge d'une manière diffuse. Enfin, quelques points noirs sont visibles sur la masse viscérale.

La première dorsale est uniformément noire. Le tiers inférieur de la deuxième dorsale est pigmenté à l'exception des pinnules. La base des rayons de la caudale l'est également. L'anale et les ventrales sont incolores. Les deux rayons supérieurs des pectorales sont colorés sur leur moitié proximale.

3.7 Spécimen de 53,1 m/m de Lf (Fig. 5)

3.7.1 Morphologie

L'aspect général est très proche de celui de 32,9 m/m, ce qui le rattache sans aucun doute à la série précédente bien qu'il n'ait pas été pêché dans les mêmes parages.

Le museau est court, busqué. Les dents sont très petites. La narine antérieure est petite, arrondie; la postérieure est en forme de fente verticale allongée (faisant le quart du diamètre de l'oeil environ). Les épines préoperculaires ont disparu; le bord du préopercule est irrégulièrement dentelé (reste des épines); les épines nuccales ne sont plus visibles. On compte 6-1-20 branchiospines sur le premier arc branchial.

Le corps est assez allongé, se rétrécissant rapidement après la deuxième dorsale. La ligne latérale est bien visible, surtout dans sa partie antérieure qui est arquée au-dessus de la pectorale. On distingue nettement les écailles sur la partie antérieure dorsale du corps.

La première dorsale est haute, avec 14 rayons épineux dont la taille décroît régulièrement du premier au dernier très petit. La deuxième dorsale, assez basse, possède 15 rayons. Les 8 pinnules qui suivent sont encore reliées par une membrane incolore à leur base. L'anale est composée de 14 rayons suivis de 8 pinnules semblables aux dorsales.

3.7.2 Coloration

Le museau est entièrement pigmentée depuis le niveau de la narine antérieure jusqu'à

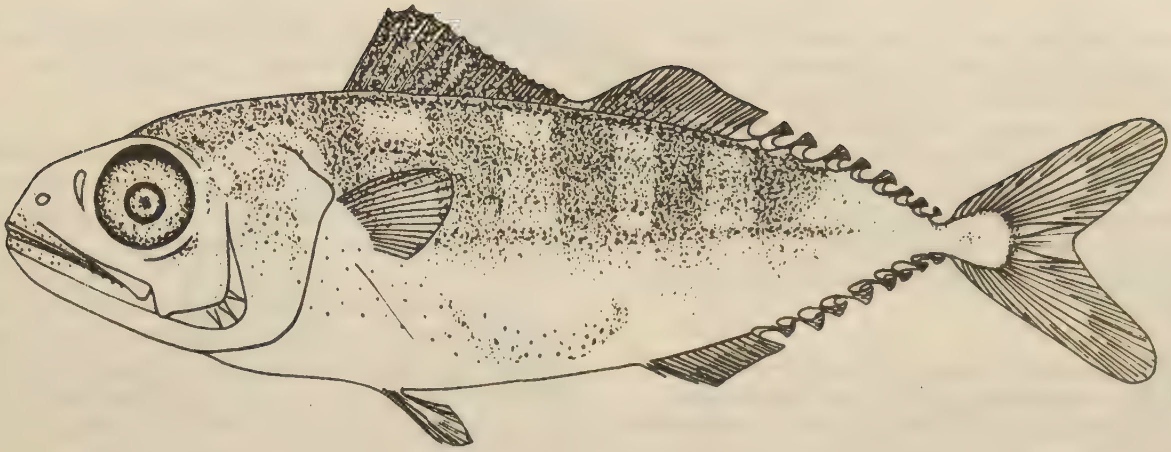

Figure 4 - Spécimen de 32, 9 m/m de Lf.
Description des stades post-larvaires et juvéniles de Neothunnus albacora (Lowe) de l'Atlantique tropico-oriental.

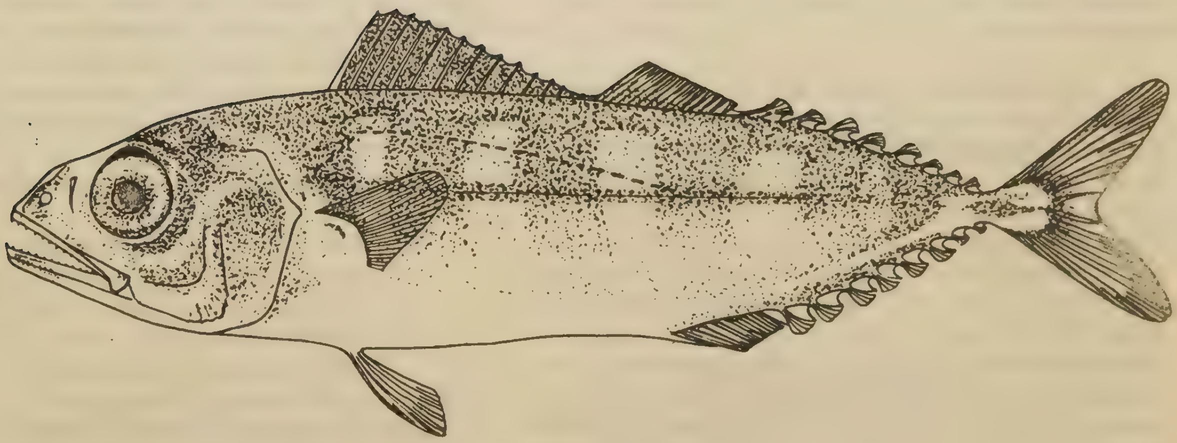

Figure 5 - Spécimen de 53, 1 m/m de Lf.
Description des stades post-larvaires et juvéniles de Neothunnus albacora (Lowe) de l'Atlantique tropico-oriental.

son extrémité. Le bord de la mâchoire supérieure également sur toute sa longueur, alors que seule, la moitié distale de la mâchoire inférieure l'est. On voit en plus, une série de petits points noirs à la commissure de la bouche. Le pourtour de l'orbite est pigmenté sauf en avant de l'oeil (région de la narine postérieure formant une plage claire). Le préopercule, l'opercule et le dessus de la tête sont à peu près entièrement pigmentés.

Les flancs sont pigmentés sur les trois-quarts de la hauteur en avant. Le niveau inférieure de cette pigmentation s'étend en ligne droite vers l'arrière pour atteindre la base de l'anale, la partie postérieure du corps étant entièrement pigmentés. Cette coloration est constituée de six bandes sombres sur le côté gauche (sept sur le côté droit) séparées par des bandes plus claires à peu près de même largeur. Le dos est entièrement sombre. La ligne médiane du corps est soulignée sur toute sa longueur par une bande transversale pigmentée. Enfin, la base de l'anale porte aussi une bande colorée.

Il faut noter que sur le poisson vivant les zones pigmentées du corps sont bleu-noir, alors que les zones claires sont argentées, coloration faisant place dans le formol à des bruns et des beiges pâles.

La première dorsale est entièrement noire. La deuxième dorsale est pigmentée dans ses deux tiers inférieurs environ, mais moins foncée que la première. Les pinnules dorsales ont 1 à 3 chromatophores sur leur bordure inférieure. Tous les rayons de la caudale sont pigmentés à leur base; de plus, le 1/5ème proximal des rayons supérieurs (sauf les petits antérieurs) et le 1/3 distal des rayons formant le lobe supérieur de cette nageoire portent des points colorés. Les pinnules anales sont incolores. L'anale est incolore à part quelques points noirs sur la partie proximale des rayons antérieurs jusqu'au dixième. Les ventrales sont incolores. Les premier et deuxième rayons de la pectorale sont pigmentés en entier; le 3ème sur le 1/3 proximal et quelques chromatophores vers l'extrémité distale; les suivants, en décroissant jusqu'au quinzième; à partir du seizième, la nageoire est entièrement incolore.

4 BIOMETRIE, EVOLUTION GENERALE DES STADES POST-LARVAIRES ET JUVENILES

Les mensurations ont été effectuées sous une loupe binoculaire à l'aide de micromètres (sauf pour certaines distances des plus grands spécimens, mesurées au compas).

Les distances sont prises entre perpendiculaires à partir du bout du museau. La hauteur de la tête est mesurée au niveau du milieu de l'oeil; les hauteurs du corps au niveau du début de la première dorsale et de la deuxième dorsale. Les épines et rayons sont mesurés de la base à l'extrémité. Les mensurations sont données au centième de millimètre: en fait, la précision ne va pas au-delà de deux à trois centièmes de millimètre. En outre, les causes d'erreur sont nombreuses, surtout chez les plus petits individus car ceux-ci sont parfois plus ou moins abimés par la fixation. Aussi, les valeurs données ne sont-elles pas toujours très exactes et une valeur aberrante n'a-t-elle rien d'anormal. Toutefois, les résultats justifient l'intérêt de ces mesures.

Les résultats des mensurations sont portés dans le tableau I donné en annexe. Le tableau II indique les valeurs des rapports effectués entre certaines de ces mensurations. L'examen de ces indices permet de se rendre facilement compte de l'évolution des différents caractères.

- Rapport I (longueur totale/longueur à la fourche caudale):
  Pendant les premiers stades, les lobes de la caudale s'allongent; ensuite, la forme de la caudale reste à peu près la même; au dernier stade, les lobes sont plus écartés.

- Rapport II (longueur totale/longueur standard):
  La longueur de la caudale par rapport au corps varie peu; elle est toutefois nettement plus petite au dernier stade, les lobes étant plus écartés.

- Rapport III (longueur à la fourche caudale/distance préanale):
  L'anale se rapproche de l'extrémité antérieure du corps jusqu'au stade 23,16 m/m, ensuite, elle s'en éloigne à nouveau.

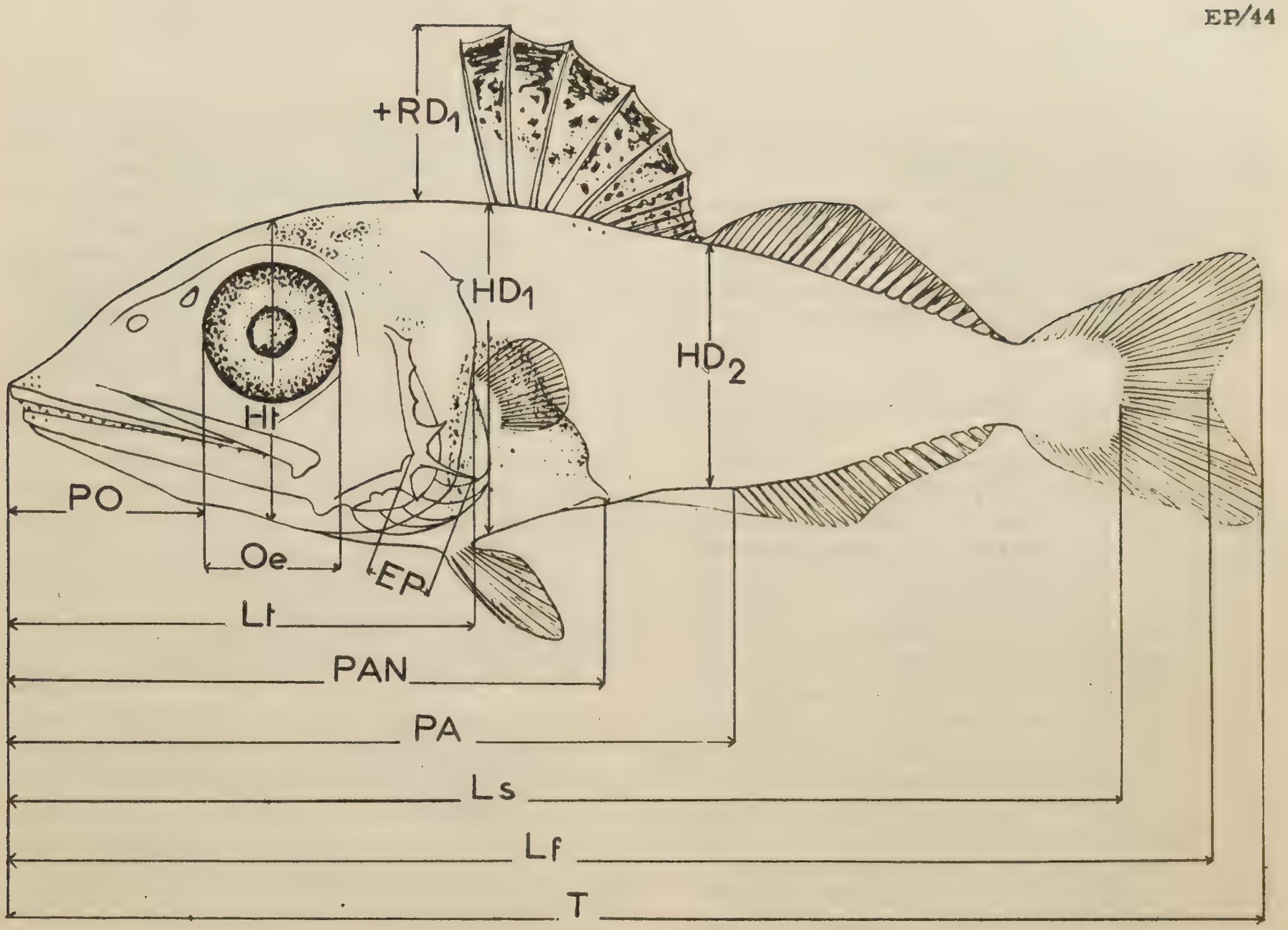

Figure 6 - Mensurations effectuées.
Description des stades post-larvaires et juvéniles de *Neothunnus albacora* (Lowe) de l'Atlantique tropico-oriental.

T : Longueur totale
Lf : Longueur à l'extremité des rayons médiaux de la fourche caudale
Ls : Longueur standard (longueur du corps)
PA : Distance préanale
PAN: Distance préanus
Lt : Longueur de la tête
oe : Diamètre de l'oeil

PO : Distance préorbitaire
Ht : Hauteur de la tête
HD_1 : Hauteur au début de la première dorsale
HD_2: Hauteur au début de la deuxième dorsale
EP : Longueur de l'épine médiane préoperculaire
$+RD_1$: Longueur du plus long rayon de la première dorsale

- Rapport IV (longueur à la fourche caudale/distance préanus):
L'anus qui est à mi-distance entre l'extrémité antérieure et postérieure au premier stade, émigre vers l'arrière au cours de la croissance, puis revient un peu en avant aux deux derniers stades.

- Rapport V (distance préanale/distance préanus):
L'anus d'abord situé bien en avant de l'anale (et relié à elle par une membrane) s'en rapproche rapidement au cours de sa migration pour l'atteindre pratiquement au stade 18,16 m/m.

- Rapport VI (longueur à la fourche caudale/hauteur de la tête):
La hauteur de la tête a été mesurée au niveau du centre de l'oeil, mais en fait dans les premiers stades, sa plus grande hauteur est plus en arrière. Ainsi, c'est bien dans ces premiers stades que la tête est la plus élevée (la plus grande hauteur du poisson étant située à ce moment-là au niveau du bord du préopercule); ensuite la hauteur de la tête diminue régulièrement pour être nettement plus petite que la hauteur du corps dans le dernier stade.

- Rapport VII (longueur à la fourche caudale/hauteur au début de D1):
Cette hauteur ne varie guère proportionnellement jusqu'à 18,16 m/m; ensuite, elle diminue (le corps s'affine de plus en plus).

- Rapport VIII (longueur à la fourche caudale/hauteur à D2):
Cette hauteur, d'abord faible, augmente assez régulièrement jusqu'au stade 15,06 m/m, plafonne ensuite jusqu'à celui de 23,16 m/m, puis diminue progressivement (affinement du corps).
Elle est toujours inférieure à la hauteur à D1.

- Rapport IX (hauteur à D1/hauteur à D2):
Ce rapport montre très clairement l'évolution caractéristique de la forme du corps chez cette espèce. La hauteur du corps diminue régulièrement d'avant en arrière dans les premiers stades (profils dorsal et ventral formant un angle assez ouvert), puis, il y a une "cassure" du profil s'accentuant au niveau de la deuxième dorsale jusqu'à 18,16 m/m, ensuite la proportion des hauteurs est à peu près constante (profils dorsal et ventral presque parallèles).

- Rapport X (longueur à la fourche caudale/longueur tête):
La tête diminue régulièrement de longueur au cours de la croissance.

- Rapport XI (longueur tête/hauteur tête):
Ce rapport est à peu près constant, sauf pour le dernier stade où la tête est nettement moins haute.

- Rapport XII (longueur tête/diamètre de l'oeil):
La constance de ce rapport montre que si l'oeil est toujours à peu près de même taille par rapport à la tête, il suit la même diminution que celle-ci par rapport à la longueur du corps (plus accentuée d'ailleurs aux deux derniers stades).

- Rapport XIII (longueur tête/distance préorbitaire):
Pendant les premiers stades, le museau a sensiblement la même longueur par rapport à la tête; à partie de 15,06 m/m, il se raccourcit nettement et constamment.

- Rapport XIV (longueur tête/épine médiane de l'armature préoperculaire):
Cette épine, longue dans les premiers stades, régresse régulièrement pour n'être plus visible au dernier.

Rapport XV (longueur tête/plus long rayon de D1):
Le plus long rayon de la première dorsale (le second) est maximum au stade 10, 86 m/m, ensuite, il diminue assez régulièrement (surtout par rapport à la longueur du corps).

D'après cette évolution, on peut dire qu'à partir de 18 m/m Lf environ, la phase post-larvaire est terminée. La forme nettement différente du corps marque le début de la phase juvénile.

5 DISCUSSION DE LA DETERMINATION

Les formes décrites ci-dessus se rapportent incontestablement à une espèce de la famille des Thunnidae (39 vertèbres, dont 18 précaudales et 21 caudales - 14 rayons épineux à la première dorsale). Trois représentants de cette famille ont été signalés dans la région géographique considérée: Neothunnus albacora (Lowe); Parathunnus obesus (Lowe); Germo alalunga (Gmelin).

L'espèce qui est de beaucoup la plus abondante est Neothunnus albacora. Parathunnus obesus est pêché régulièrement au large, à l'aide de long-lignes, mais il s'agit seulement de très gros individus pris à une certaine profondeur, jamais de jeunes: il semble que l'on soit en présence d'individus obéissant à une migration trophique. Quant à Germo alalunga, c'est tout récemment seulement que nous avons pu en voir à Abidjan, pêchés également aux long-lignes à 200 milles au large des côtes africaines environ. Il s'agit là encore, de gros individus aux organes reproducteurs au repos (pour ceux que nous avons observés), jamais vus en surface et vraisemblablement en migration trophique.

En définitive, la seule espèce dont on trouve des individus de toute taille, toute l'année, et étant dans son aire de répartition normale est Neothunnus albacora.

Toutes ces considérations ne peuvent évidemment fournir que des présomptions. Examinons donc, maintenant, les caractères discriminatoires de ces espèces.

En ce qui concerne le nombre de rayons de nageoires, il y a peu de différences entre ces 3 espèces. Toutefois, en général, Parathunnus possède 9 pinnules dorsales et ventrales, alors que Germo et Neothunnus en ont le plus souvent 8, ce qui est le cas pour nos spécimens.

En ce qui concerne le nombre de branchiospines, Parathunnus en a généralement 17 à 19 sur la branche inférieure du premier arc branchial (toujours compte non tenu de la branchiospine médiane). Germo en a 18 à 20, Neothunnus 20 à 23. Notre exemplaire de 32, 9 m/m en a 19, celui de 53, 1 m/m en a 20. Parathunnus pourrait donc être éliminé, d'autant qu'il est très vraisemblable que le nombre de branchiospines croisse encore avec la taille au delà de 53 m/m: ce qui nous permet d'éliminer, avec doute, Germo.

Comparons nos descriptions avec celles d'autres auteurs:

Ehrenbaum, d'après Padoa, a décrit une série de post-larves de 4, 5 m/m à 15, 5 m/m de longueur totale, qu'il rapporte à l'espèce Germo alalunga. Si ces formes ont une indiscutable parenté avec les nôtres, il semble toutefois qu'il y ait un certain nombre de différences: à la taille égale, la forme de la première dorsale n'est pas la même; notamment, notre exemplaire de 13, 85 m/m de longueur totale montre une échancrure en V entre la première et la deuxième dorsales, alors que l'exemplaire de 13, 5 m/m de Ehrenbaum possède une première dorsale dont les 10 premiers rayons vont en décroissant, puis les 4 suivants égaux, ce qui donne une échancrure beaucoup plus large. De même, la forme générale du corps semble quelque peu différente, la "cassure" du profil dorsal étant déjà beaucoup plus marquée sur l'exemplaire de Ehrenbaum que sur le nôtre qui est, cependant, légèrement plus grand. Enfin, les épines préoperculaires semblent plus réduites.

Charles B. Wade a publié la description de formes larvaires, post-larvaires et juvéniles de Neothunnus macropterus. Nos exemplaires se rapprochent beaucoup de ceux décrits par cet auteur, tant pour les post-larves que pour les stades juvéniles: Par exemple, la coloration typique en bandes verticales commence à être visible dans le spécimen de 23 m/m représenté; sur notre spécimen de 23, 16 m/m, on voit également l'amorce de 4 bandes verticales.

En conclusion de ce chapitre, nous pouvons dire qu'il est hautement probable que les stades post-larvaires et juvéniles décrits dans ce travail soient bien ceux de l'espèce Neothunnus albacora.

TABLEAU I - MENSURATIONS en m/m

N	T	Lf	Ls	PA	PAN	Lt	Ht	HD_1	HD_2	Oe	PO	EP	+ RD_1
1	10,26	9,87	8,95	5,82	4,93	3,83	2,76	2,88	1,86	1,34	1,52	0,66	1,41
2	10,99	10,40	9,48	6,05	5,40	4,10	2,93	2,83	1,93	1,40	1,55	0,52	1,52
3	Exemplaire coloré à l' Alizarine												
4	11,52	10,86	10,00	6,51	5,72	4,00	3,28	3,03	2,21	1,41	1,59	0,41	1,72
5	12,50	11,45	10,66	7,11	6,45	4,28	3,38	3,45	2,83	1,55	1,66	0,72	2,03
6	13,82	12,93	11,84	7,89	7,04	4,87	3,82	3,70	3,03	1,76	1,90	0,65	1,93
7	15,13	14,08	12,89	8,95	8,55	5,39	4,08	4,08	3,42	1,90	2,07	0,76	2,21
8	16,25	15,06	13,82	9,47	9,21	5,79	4,14	4,47	3,95	2,10	2,00	0,69	2,48
9	17,77	16,50	15,46	10,33	9,87	6,19	4,54	4,87	4,08	2,24	2,24	0,69	2,34
10	18,82	17,50	16,19	10,79	10,53	6,45	4,47	4,87	4,21	2,41	2,24	0,65	2,31
11	19,74	18,16	16,97	11,58	11,45	6,19	4,47	5,00	4,61	2,34	2,07	0,72	2,76
12	24,74	23,16	21,58	15,00	14,74	7,40	5,45	6,19	5,79	2,62	2,28	0,72	3,28
13	35,3	32,9	30,8	19,6	19,4	10,26	6,84	9,74	7,90	3,22	2,90	0,76	3,28
14	55,9	53,1	50,0	31,1	30,7	14,3	8,2	11,8	11,0	4,5	3,8	-	5,65

TABLEAU II - RAPPORTS DES MENSURATIONS

N	T	Lf	T/Lf	T/Ls	Lf/PA	Lf/PAN	PA/PAN	Lf/Ht	Lf/HD$_1$	Lf/HD$_2$	HD$_1$/HD$_2$	Lf/Lt	Lt/Ht	Lt/oe	Lt/Po	Lt/EP	Lt/+RD$_1$
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
1	10,26	9,87	1,04	1,15	1,70	2,00	1,18	3,58	3,43	5,31	1,55	2,58	1,39	2,86	2,52	5,00	2,72
2	10,99	10,40	1,06	1,16	1,72	1,93	1,12	3,55	3,67	5,39	1,47	2,54	1,40	2,93	2,65	7,88	2,70
3	11,3	10,8	Exemplaire coloré à l'Alizarine —														
4	11,52	10,86	1,06	1,15	1,67	1,90	1,14	3,31	3,58	4,91	1,37	2,71	1,22	2,84	2,52	9,76	1,97
5	12,50	11,45	1,09	1,17	1,61	1,78	1,10	3,39	3,32	4,05	1,22	2,68	1,27	2,76	2,58	5,94	2,11
6	13,82	12,93	1,07	1,17	1,64	1,84	1,12	3,38	3,49	4,27	1,22	2,66	1,27	2,77	2,56	7,49	2,52
7	15,13	14,08	1,07	1,17	1,57	1,65	1,05	3,45	3,45	4,12	1,19	2,61	1,32	2,84	2,60	7,09	2,44
8	16,25	15,06	1,08	1,175	1,59	1,64	1,03	3,64	3,37	3,81	1,13	2,60	1,40	2,76	2,89	8,39	2,33
9	17,77	16,50	1,08	1,15	1,60	1,67	1,05	3,63	3,39	4,04	1,19	2,67	1,36	2,76	2,76	8,97	2,65
10	18,82	17,50	1,08	1,16	1,62	1,66	1,024	3,91	3,59	4,16	1,16	2,71	1,44	2,68	2,88	9,92	2,79
11	19,74	18,16	1,09	1,16	1,57	1,59	1,01	4,06	3,63	3,94	1,08	2,93	1,38	2,65	2,99	8,60	2,24
12	24,74	23,16	1,07	1,15	1,54	1,57	1,02	4,25	3,74	4,00	1,07	3,13	1,36	2,82	3,25	10,28	2,26
13	35,30	32,90	1,07	1,15	1,68	1,70	1,01	4,81	3,83	4,22	1,10	3,29	1,46	3,08	3,45	13,16	3,05
14	55,9	53,1	1,05	1,12	1,71	1,73	1,01	6,48	4,50	4,83	1,07	3,71	1,74	3,18	3,76	-	2,53

Experience Paper No. 45

RESULTADOS DEL PROGRAMA DE MARCADO DE ATUN EN AGUAS ESPANOLAS

por

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Extracto

Hasta ahora se han marcado y soltado en la costa meridional de España 162 atunes rojos. En mayo y junio esta especie de atun va hacia el Mediterraneo mientras que en julio y agosto va hacia Portugal y Noruega. En 1960 el porcentaje de ejemplares recuperados fue del 18, 9 por ciento y en 1961 del 5 por ciento.

RESULTS OF THE TUNA TAGGING PLAN IN SPANISH WATERS

Abstract

One hundred and sixty two bluefin tuna were tagged and released on the south coast of Spain. In May and June the bluefin tuna moves towards the Mediterranean Sea while in July and August to Portugal and Norway. In 1960 and 1961 the percentage of recoveries was 18, 9 and 5 percent.

RESULTATS D'UN PROGRAMME DE MARQUAGE DES THONS DANS LES EAUX ESPAGNOLES

Résumé

On a procédé à ce jour sur la côte sud de l'Espagne au marquage et à la remise à l'eau de 162 thons rouges. En mai et juin, cette espèce se dirige vers la Méditerranée, tandis qu'en juillet et août elle s'oriente vers le Portugal et vers la Norvège. Le pourcentage des recaptures a été de 18, 9 pour cent en 1960 et de 5 pour cent en 1961.

1 INTRODUCCION

En las costas sudatlánticas españolas, se captura el atún, Thunnus thynnus, en grandes cantidades por medio de almadrabas. Estas capturas comienzan en el mes de mayo y terminan a mediados del de agosto. En la costa mediterránea española y a la entrada del Estrecho de Gibraltar existe otra almadraba que captura atunes a partir del mes de julio.

Se distinguen dos clases de atunes el de "derecho", y el de "revés", el primero es aquel que aparece a principios de temporada, de mayo a finales de junio, llega con las gonadas repletas, el cuerpo lleno de grasa y lleva dirección oeste-este; el segundo se captura a partir del mes de julio hasta mediados agosto, tiene sus órganos sexuales vacios, el cuerpo sin grasa y lleva dirección este-oeste, remontando más tarde las costas europeas hasta Noruega.

El número actual de almadrabas funcionando en estas costas es de 5, de la cuales 1 está situada en las costas de Juelva, 3 en las de Cádiz y 1 en el Mediterráneo a la entrada misma del Estrecho de Gibraltar. En la campaña de 1961 se capturaron un total de más de 4 millones de kilógramos entre todas ellas.

2 MATERIAL Y METODOS

Hasta ahora se han marcado un total de 162 atunes de los cuales 37 lo fueron en el año 1960, 100 en 1961 y 25 en mayo de 1962, faltando marcar 25 mas en el mes de julio o agosto de éste año, lo que hará un total de 187 atunes. Todos ellos fueron marcados en la almadraba de Barbate (Cádiz), excepto los 5 primeros que lo fueron en la de Sancti-Petri (Cádiz). En el mapa (Fig. 1), se señalan los lugares (Isla Cristina, Sancti-Petri, Barbate, Tarifa y La Línea) en que estan situadas las almadrabas.

El método empleado es el de Hamre (1959), es decir que por medio de una larga caña se le introduce un arpón en el lomo del atún, cerca de la segunda aleta dorsal. El arpón es de nylon así como el hilo que lo une a la cápsula transparente de plástico (Lea tag), la cual lleva en su interior un papel impreso con un texto y las señas para su devolución. Las marcaciones se hicieron en la misma almadraba y el atún permanece fuera del agua como máximo 15 segundos. En la figura 2, se dan detalles del arpón, marca y pértiga y de una tabla de 2 metros de longitud para poner el atún encima marcarlo y deslizarlo al agua rápidamente y sin daño alguno. Dicha tabla se ata por su extremo a a la red del copo de la almadraba y el extremo b es el que se levanta para que se deslice el atún al mar libre.

3 MARCADO Y RECAPTURAS

En el cuadro I se dan la localidad, fecha y otros datos de los atunes marcados y recapturados. Para 1960 el número de atunes recapturados hasta la fecha representa al 18'9%, y para 1961, el 5%. Todos los atunes fueron libertados en buenas condiciones fisicas (Figs. 3, 4, 5, 6, 7, 8). Hay que tener en cuenta la pérdida de las marcas debido a varias causas, ya sea por simple desprendimiento, por roce con algún obstáculo o por muerte del atún, y así tenemos dos casos, uno el de un atún marcado el 14 de junio de 1961, cuya marca fué hallada en el estómago de otro atún capturado en Barbate el 23 de julio de 1961, es decir a los 23 dias, y el del atún marcado el 14 de junio de 1961 apareciendo su marca en la playa de Algeciras, cerca de Gibraltar.

Algunas veces parece que el atún marcado al liberarlo no huye de la zona del marcado sino que permanece en ella como lo demuestra el caso del pequeño atún marcado el 24 de mayo de 1960 en Barbate, de unos 70 cm. de longitud, que apareció en la misma almadraba el 28 de mayo de 1960 es decir a los 4 dias y al que se le volvió a dar la libertad por segunda vez.

4 MIGRACION

El atún de "derecho" es decir el que aparece en las costas sudatlánticas españolas en el mes de mayo se dirige al Mar Mediterráneo, atravesando el Estrecho de Gibraltar como lo demuestran los ejemplares 2, 4 y 8, que fueron a parar finalmente a La Línea, Grau du Roi y Ceuta, al cabo de 64, 85 y 19 días respectivamente. Estos atunes fueron marcados en el "derecho" es decir a comienzos de la temporada y reanudaron su ruta hacia el este como estaba previsto. Sin embargo hubieron algunas excepciones a lo indicado y así vemos que los ejemplares 1 y 13 a pesar de ser de "derecho" y estar marcados en el mes de mayo, cambiaron de rumbo y se dirigieron en dirección opuesta yendo a parar a la almadraba de Tavira (Portugal) el primero al dia siguiente y el segundo a los 2 dias. El primero de los citados ultimamente, el número 1, recorrió la distancia Barbate - Tavira, cerca de 200 kilómetros per hora. Hubo un atún, el número 3 que marcado en Barbate el 28 de mayo de 1960 fué capturado al dia siguiente en la misma almadraba, pareciendo indicar o una merma en sus facultades físicas debidas al marcado o que se agregó a un cardumen recien llegado a la almadraba.

Respecto a los atunes de "revés" todos los marcados siguieron su habitual rumbo a poniente, como lo indican los números 6, 7, 9, 10 y 12 que marcados en Barbate se dirigieron a Portugal unos y otros a las costas españolas mas occidentales. Hubo una excepción el número 11, que marcado el 20 de julio de 1961, fué recapturado en la misma almadraba el 23 de julio de 1961, es decir a los 316 dias, lo cual indica que este atún despues de liberado en Barbate siguió hacia las costas portuguesas y probablemente se dirigió despues hacia el norte de Europa en busca de alimento y reparar sus gastadas fuerzas, para luego invernar en algún lugar del atlántico, hasta que llegada la primavera, inició de nuevo su camino hacia el Mar Mediterráneo, pasando cerca de Larache donde fué recapturado. Que el atún sigue la ruta de Noruega, parece indicarlo la recaptura en aguas españolas del Golfo de Cádiz de atunes marcados en ese nórdico pais (Rodriguez-Roda, 1959).

Cuadro I

Datos de los atunes (*Thunnus thynnus*) marcados y recapturados en aguas españolas

M A R C A C I O N				R E C A P T U R A				
Recaptura Nº	Localidad del Golfo de Cádiz	Fecha	Fase	Localidad	Fecha	Long. zool. cm	Peso Kg	Dias en libertad
1	Sancti-Petri	23 mayo 1960	"Derecho"	Tavira (Portugal)	24 mayo 1960	170	110	1
2	Barbate	24 mayo 1960	"Derecho"	La Línea (España)	27 julio 1960	173	90	64
3	Barbate	28 mayo 1-60	"Derecho"	Barbate (España)	29 mayo 1960	188	102	1
4	Barbate	28 mayo 1960	"Derecho"	Grau du Roi (Francia)	21 agosto 1960	136	41	85
5	Barbate	27 julio 1960	"Revés"	Larache (Marruecos)	8 junio 1961	-	100	316
6	Barbate	27 julio 1960	"Revés"	Faro (Portugal)	25 mayo 1961	190	120	302
7	Barbate	27 julio 1960	"Revés"	Isla Cristina (España)	7 agosto 1960	174	70	11
8	Barbate	13 junio 1961	"Derecho"	Ceuta (Marruecos)	2 julio 1961	195	83	19
9	Barbate	14 julio 1961	"Revés"	Tavira (Portugal)	18 julio 1961	-	90	4
10	Barbate	14 julio 1961	"Revés"	Isla Cristina (España)	19 julio 1961	-	-	5
11	Barbate	20 julio 1961	"Revés"	Barbate (España)	23 julio 1961	147	53	3
12	Barbate	12 julio 1961	"Revés"	Sancti-Petri (España)	21 mayo 1962	156	80	313
13	Barbate	22 mayo 1962	"Derecho"	Tavira (Portugal)	24 mayo 1962	133	44	2

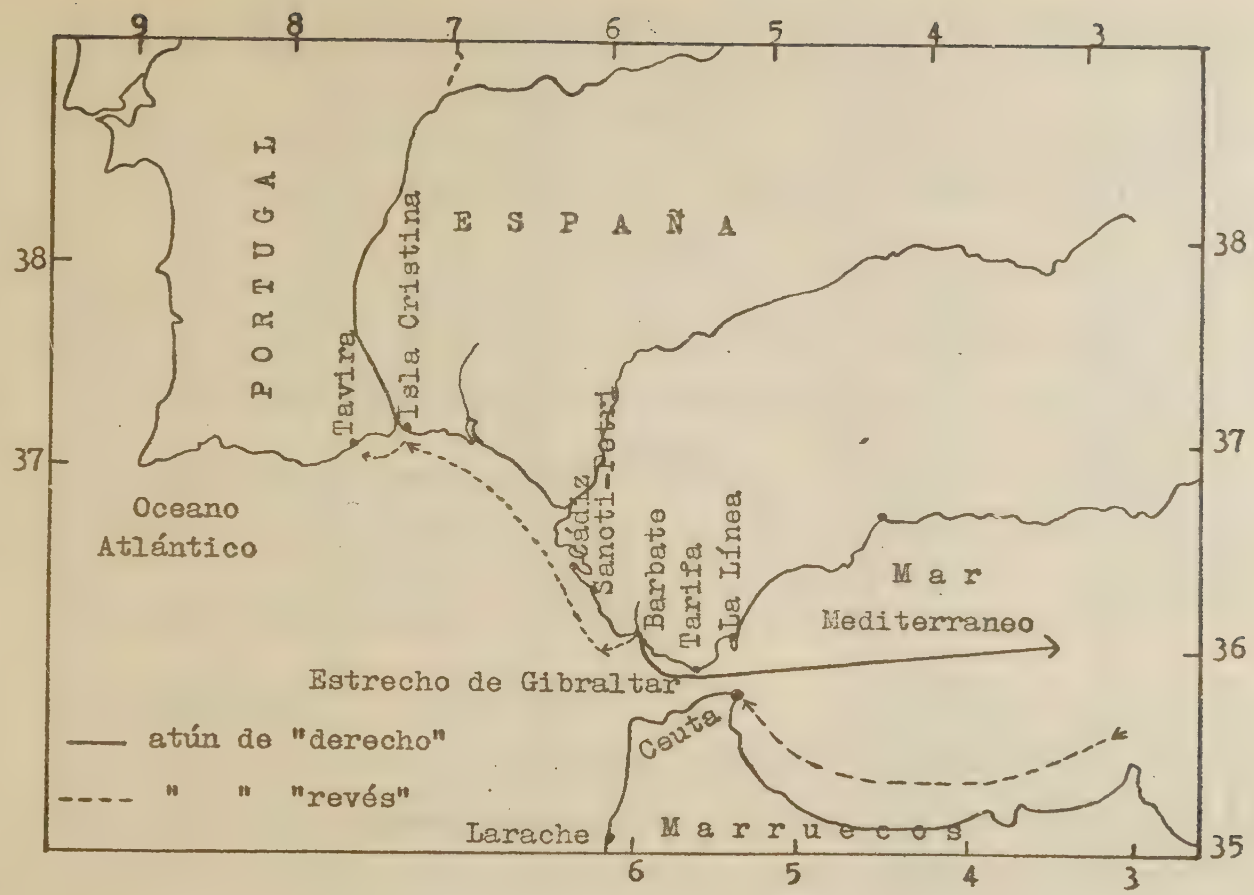
9
8
7
6
5
4
3
38
37
36
35
P O R T U G A L
E S P A Ñ A
Tavira
Isla Cristina
Cádiz
Sancti-Petri
Barbate
Tarifa
La Línea
Oceano Atlántico
Mar Mediterraneo
Estrecho de Gibraltar
Ceuta
Larache
M a r r u e c o s
atún de "derecho"
" " "revés"

Fig. 1. Localidades del Golfo de Cádiz, en que se calan almadrabas para la captura del atún, y dirección más probable seguida según las recapturas

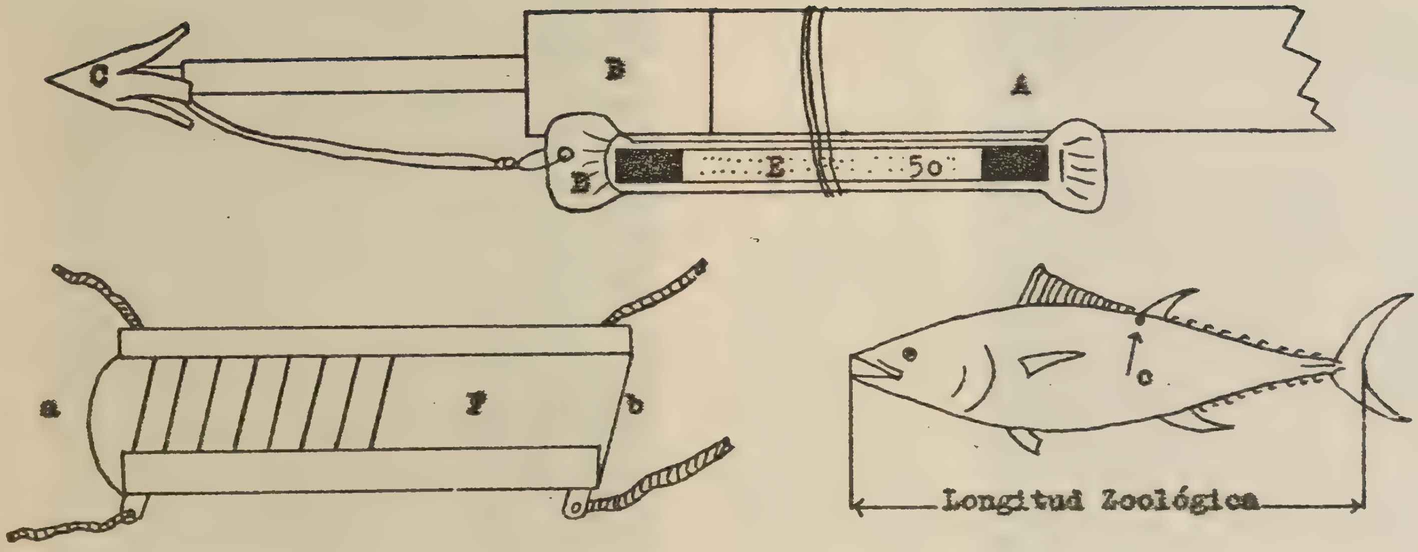
C
B
A
E
50
E
a
F
b
o
Longitud Zoológica

Fig. 2. Pértiga, arpón y tabla usados en la marcación del atún, en aguas de Barbate, en 1961

Fig. 3. Captura de un atún en el copo de la almadraba de Barbate

Fig. 4. Sujetando al atún para subirlo a la tabla del marcado

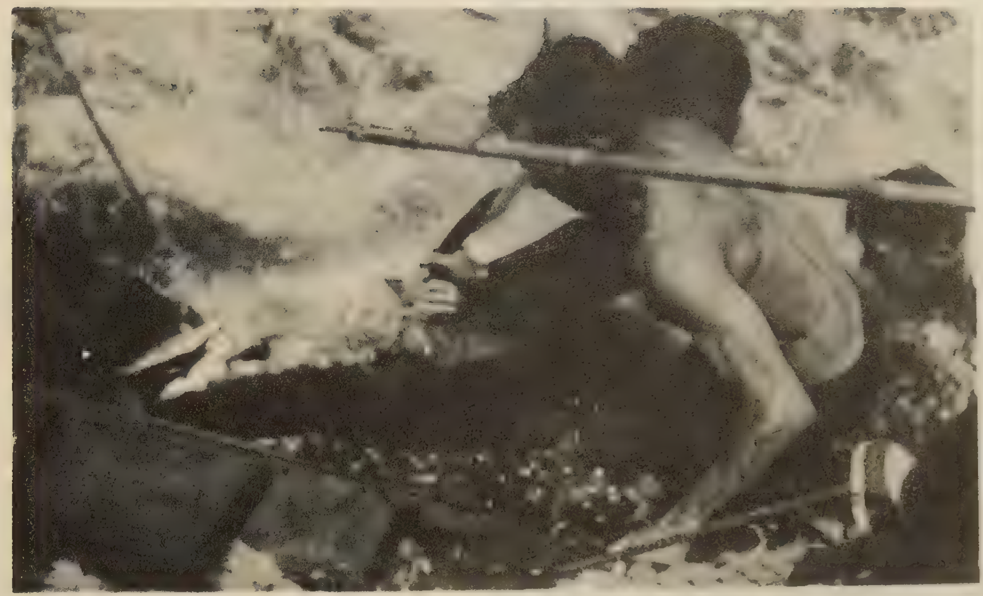

Fig. 5. Colocación del atún en la tabla del marcado

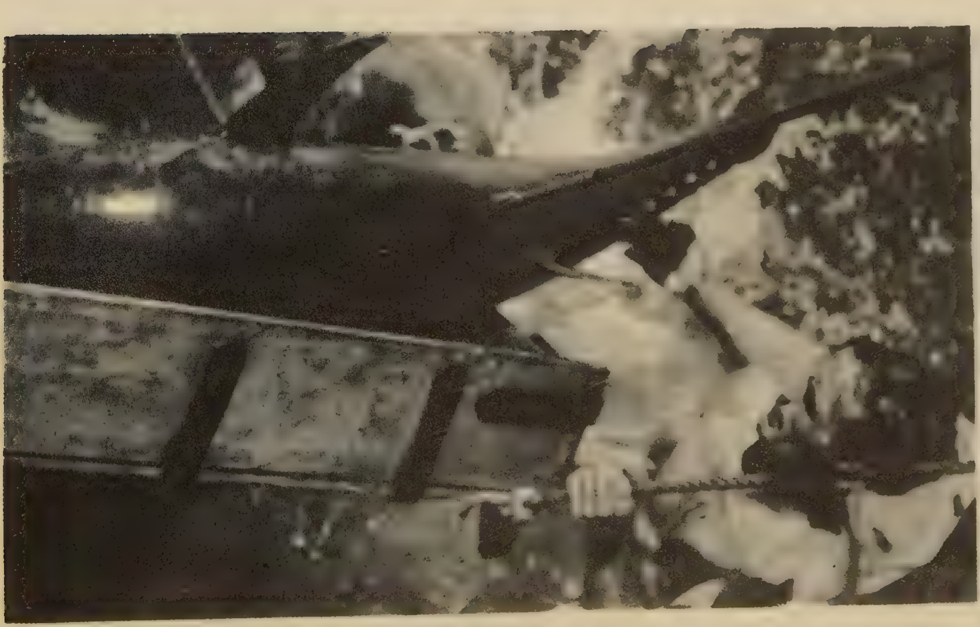

Fig. 6. Momento del marcado del atún a la altura de la segunda aleta dorsal

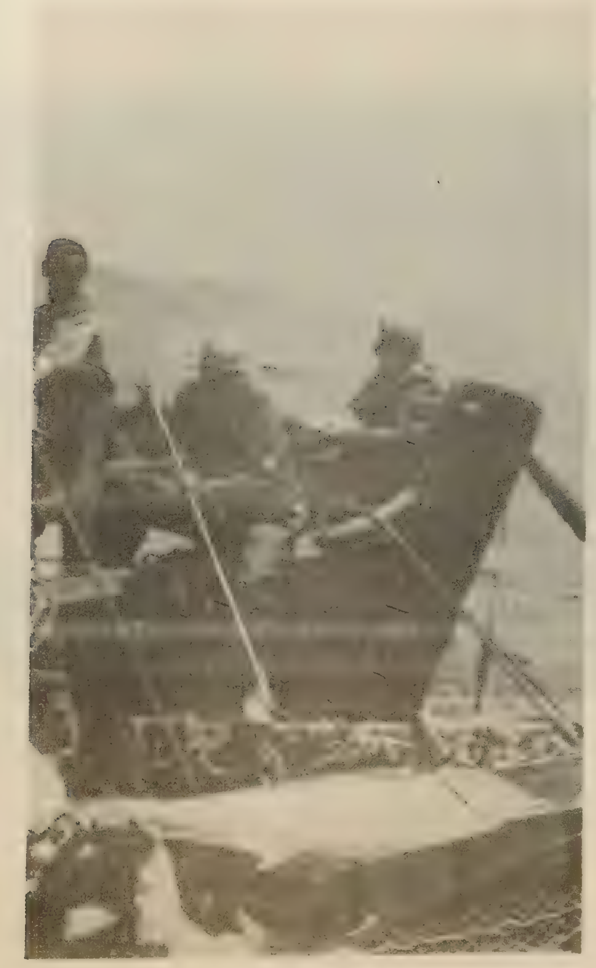

Fig. 7. Momento del marcado del atún

Fig. 8. Atún ya marcado y deslizandose al mar libre

Experience Paper No. 46

TALLA, PESO, EDAD Y CRECIMIENTO DEL ATUN DEL GOLFO DE CADIZ, ESPANA

por

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Extracto

Se estudian la edad, talla y peso de 890 ejemplares de atún, Thunnus thynnus (L.) capturados por las almadrabas de Barbate, Sancti-Petri e Isla Cristina en la costa meridional de España, durante el año 1961. La edad se estudia por las vertebras de los atunes capturados en los años 1956-1959, en Barbate.

LENGTH, WEIGHT, AGE AND GROWTH OF TUNA FROM GOLFO DE CADIZ, ESPANA

Abstract

The age, length and weight of 890 specimens of Thunnus thynnus (L.) caught by traps in Barbate, Sancti-Petri and Isla Cristina in the South coast of Spain, during the year 1961 are studied. Age is studied from vertebrae from tuna caught in 1956-1959 in Barbate.

EP/46

LONGUEUR, POIDS, AGE ET CROISSANCE DES THONS DU GOLFE DE CADIZ, ESPAGNE

Résumé

La communication étudie l'âge, la longueur et le poids de 890 spécimens de *Thunnus thynnus* (L.) capturés en 1961 dans les trappes à thons de Barbate, de Sancti-Petri et d'Isla Cristina, sur la côte sud de l'Espagne. Les données sur l'âge provenant de l'examen des vertèbres se rapportent à des thons pêchés à Barbate de 1956 à 1959.

1 INTRODUCCION

En las costas sudatlánticas españolas, se capturan grandes cantidades de atunes, Thunnus thynnus, en las almadrabas situadas en Isla Cristina, Sancti-Petri, Barbate y Tarifa (fig.1). En la costa surmediterranea y a la misma entrada del Estrecho de Gibraltar, hay otra almadraba en La Línea que tambien captura atunes pero en mucha menos cantidad. Para dar idea de la producción basta señalar que las tres primeras citadas capturaron en el año 1961, un total de 4.221.540 kilógramos. La campaña atunera en estas costas comienza en el mes de mayo y termina en el de agosto. De mayo a fines de junio se captura el atún denominado de "derecho" es decir el que viene del pleno atlántico y se dirige a las costas surespañolas en varias direcciones, unos pasando por las costas de Larache (Marruecos occidental) para despues ir hacia Tarifa y pasar al Mar Mediterráneo, otros a Barbate y Sancti-Petri, y despues al Mediterráneo y otros pocos hacia Isla Cristina. Todos estos atunes de "derecho" llegan muy gruesos, con pocas ganas de comer, y con las gonadas en período de activa madurez. Durante el mes de julio hasta fines de agosto aparece el atún de "revés" que se dirige en dirección oeste, es decir a las costas portuguesas para luego remontar hacia el norte de Europa. Estos atunes de "revés" llegan flacos, es decir sin grasa en el cuerpo, con las gonadas vacias, es decir en fase de postpuesta y con gran voracidad.

La mayor parte de los estudios se verificaron en la almadraba de Barbate y únicamente en el año 1961 se hicieron algunos en los de Sancti-Petri e Isla Cristina.

2 MATERIAL Y METODOS

El presente trabajo lo componen el estudio de 890 ejemplares, de los cuales 440 corresponden a Barbate, 338 a Sancti-Petri y 112 a Isla Cristina. La longitud medida es la zoológica, (Rodriguez-Roda, 1957) es decir la distancia recta entre el hocico y los radios centrales cartilaginosos de la aleta caudal. Estas mediciones se tomaron con un calibrador (Rodríguez-Roda, 1957) con una aproximación al medio centímetro más cercano. Los pesos se tomaron con una aproximación del kilógramo, excepto para los más pequeños que lo fué entonces del gramo.

3 TALLA, PESO Y SU RELACION

En el cuadro I. y fig. 2 se da la distribución de tallas en porcentajes y para el año 1961, de los atunes capturados en Barbate, Sancti-Petri e Isla Cristina. Se observa que la longitud media oscila alrededor de los 194 centímetros, siendo los más pequeños los que se capturan en la almadraba de Isla Cristina. La amplitud de las tallas varía de los 115 cm a los 250 cm. Con el objeto de averiguar si había diferencia de talla entre los atunes que en el curso de la campaña van llegando a las distintas almadrabas, se estudió las frecuencias de tallas por decenas, cuadro II. Si nos fijamos en Barbate, se observa que durante la fase del "derecho" la talla media del atún va disminuyendo de tal forma que a principios de temporada el atún es mayor que a fines del mes de junio, y al comenzar el "revés" ocurre lo mismo es decir el atún que aparecé a principio del mes de julio es tan grande o mayor incluso que el principio del de "derecho", para disminuir paulatinamente hasta fines de agosto. Unicamente hay que hacer notar una alteración a esta regla y es el atún aparecido la segunda decena de junio cuya talla era superior incluso al del comienzo de temporada, probablemente se debió a una entrada de grandes atunes que venian retrasados o procedian de otro lugar distinto al habitual. Para la almadraba de Sancti-Petri ocurre igual con la misma anomalía señalada para Barbate, en la segunda decena de junio que aquí se prolonga a la tercera decena del mismo mes. Esta almadraba no captura atún de "revés". En la almadraba de Isla Cristina la regla es perfecta sin anomalía alguna. Este fenómeno de aparecer primero los ejemplares grandes, se debe probablemente a la tendencia general de los animales gregarios cuando emigran en cuyo momento los animales más viejos y experimentados son los que van en cabeza, tambien es posible influyan el desarollo de las gonadas, las cuales maduran antes en los ejemplares grandes que en los pequeños.

En el cuadro III y fig. 3 se da la distribución de los pesos, en porcentajes, y para el año 1961 de los atunes de las almadrabas antes indicadas, habiendose separado los de "derecho" de los de "revés" debido a la pérdida de peso en estos últimos como se indicó al principio. El peso medio de los atunes de "derecho" para Barbate y Sancti-Petri está alrededor de los

142, 5 kg y de 132, 4 para los de Isla Cristina. En el "revés" la disminución es sensible oscilando alrededor de los 123 kg como media.

En el cuadro IV se dan los pesos medios por cada talla para el atún de Barbate, como representativo de las tres almadrabas. Claramente se observa la pérdida de peso del atún al pasar de "derecho" a "revés", siendo esta pérdida del 16, 4% de promedio.

4 EDAD Y CRECIMIENTO

A base de 491 atunes estudiados durante los años 1956, 1957, 1958 y 1959, y por medio de las vértebras, se calculó la talla correspondiente a cada edad. En el cuadro V se da la talla media para cada edad. En la figura 1, se señalan las edades para cada talla de los atunes capturados en 1961 para las tres almadrabas estudiadas. Se observa en todas ellas un predominio de los atunes de 8 años, seguido de los de 9, siendo los atunes más pequeños que se capturan los de 5 años, aunque a veces aparecen algunos de 4 años, y los más grandes los de 12, sin embargo hay que tener en cuenta que los atunes de 13 años y más, es muy dificil leer la edad en sus vértebras. En el cuadro VI se dan para Barbate y para el año 1961, los porcentajes de los atunes que corresponden a cada edad.

Siguiendo a Walford (1946) se calculó el crecimiento límite del atún para los años 1956-1959, resultando $l_{\infty} = 355,84$ cm. El mayor atún medido por mi tenía una talla de cerca de 300 cm, sin embargo ha aparecido alguna vez atunes de una talla algo superior a los 3 metros. Aplicando la ecuación de Von Bertalanffy (Ricker 1958) se pueden obtener las tallas calculadas para cada edad, cuadro VII la ecuación de Von Bertalanffy resultó:

$$l_t = 355,84 \left[1 - e^{-0,09(t + 0,89)}\right]$$

a partir de la cual se calcularon las tallas téoricas para cada edad, que como se observa los valores son muy concordantes.

El atún crece muy rápidamente sobre todo en sus primeros estadios. A mediados del mes de septiembre, las almadrabas de La Línea y Ceuta capturan ya atunes de 30 cm de longitud zoológica como media y en noviembre los barcos de pesca de Barbate capturan al cerco, en aguas de Larache atunes de 40 cm de longitud zoológica. Las vértebras de estos atunes carecen de anillos invernales, y son animales de 4 a 5 meses de vida tan sólo. En junio de 1958, tuve oportunidad de estudiar en Barbate 25 atunes de 52 a 58 cm de longitud zoológica, y observadas sus vértebras en todas ellas habia unicamente un anillo invernal.

5 CONCLUSIONES

La talla media de los atunes que se capturaron en 1961 en las almadrabas españolas es de 194 cm que corresponde a una edad de 8 años. El peso medio de 142 kg para los de "derecho" y 122 kg para los de "revés". Los atunes que se capturan al comienzo del "derecho" y "revés", es decir en los meses de mayo y julio respectivamente, son mayores que los de finales de estas dos fases, o sea junio y agosto.

La edad de los atunes mas frecuentes que se capturan es la de 8 años. En los meses de septiembre a noviembre y diciembre se pescan atunes de 30 a 40 cm de longitud que no llegan al medio año de vida.

Cuadro I

Porcentaje de las frecuencias de tallas del atún, *Thunnus thynnus* del año 1961. (cm)

Intervalos de clase cm	Barbate	Sancti-Petri	Isla Cristina
115 - 119'5	-	0'29	-
120 - 124'5	-	-	-
125 - 129'5	-	-	-
130 - 134'5	0'23	0'29	0'89
135 - 139'5	-	-	0'89
140 - 144'5	0'45	2'96	-
145 - 149'5	1'36	1'48	5'36
150 - 154'5	2'95	2'66	3'57
155 - 159'5	3'18	3'25	0'89
160 - 164'5	2'27	1'77	2'68
165 - 169'5	0'91	0'29	-
170 - 174'5	1'82	0'59	-
175 - 179'5	2'73	2'73	3'57
180 - 184'5	6'36	6'51	7'14
185 - 189'5	10'68	10'65	14'28
190 - 194'5	15'68	13'61	14'28
195 - 199'5	13'18	15'98	13'39
200 - 204'5	12'27	10'95	13'39
205 - 209'5	9'54	7'10	4'46
210 - 214'5	5'91	5'92	3'57
215 - 219'5	4'54	3'25	1'78
220 - 224'5	2'73	2'37	6'25
225 - 229'5	1'82	2'96	-
230 - 234'5	0'45	0'89	-
235 - 239'5	0'68	1'48	1'78
240 - 244'5	-	1'18	0'89
245 - 249'5	0'23	0'89	0'89
250 - 254'5	-	0'29	-
	99'97	99'98	99'95
No. total	440	338	112
Long. media	194'10	194'45	192'01
Desviación típica	18'50	22'00	21'75
Error típico medio	0'88	1'20	2'05

Cuadro II

Tallas medias, por decenas, Thunnus thynnus (cm)

	Barbate	Sancti-Petri	Isla Cristina
" Derecho"			
11 - 20 mayo 1961	196'1	196'8	-
21 - 31 mayo 1961	193'5	195'2	-
1 - 10 junio 1961	192'1	180'6	188'6
11 - 20 junio 1961	205'8	193'1	182'5
21 - 30 junio 1961	192'5	197'6	-
" Revés"			
1 - 10 julio 1961	201'9	-	206'1
11 - 20 julio 1961	197'4	-	-
21 - 31 julio 1961	190'4	-	204'5
1 - 10 agosto 1961	191'0	-	-
11 - 20 agosto 1961	-	-	160'8

Cuadro III

Porcentaje de las frecuencias de pesos del atún, Thunnus thynnus del año 1961. (kg)

Intérvalos de clase kg	BARBATE		SANCTI -PETRI	ISLA CRISTINA	
	"Derecho"	"Revés"	"Derecho"	"Derecho"	"Revés"
35 - 39'5	-	-	0'51	-	-
40 - 44'5	-	-	0'51	-	-
45 - 49'5	-	-	-	2'17	-
50 - 54'5	-	0'85	0'51	-	4'61
55 - 59'5	-	1'71	1'52	-	1'54
60 - 64'5	-	2'14	1'52	-	4'61
65 - 69'5	1'29	2'56	1'01	4'35	3'08
70 - 74'5	1'93	1'71	1'52	4'35	1'54
75 - 79'5	1'93	1'71	0'51	-	-
80 - 84'5	3'22	-	2'54	2'17	-
85 - 89'5	2'58	0'43	-	-	-
90 - 94'5	0'64	2'99	2'03	-	1'54
95 - 99'5	0'64	5'55	-	2'17	-
100 - 104'5	0'64	7'26	0'51	-	1'54
105 - 109'5	0'64	7'69	0'51	2'17	4'61
110 - 114'5	4'52	5'98	5'08	-	15'38
115 - 119'5	3'22	9'40	3'55	8'69	9'23
120 - 124'5	5'16	6'41	4'06	2'17	10'77
125 - 129'5	6'45	6'84	5'58	10'87	6'15
130 - 134'5	6'45	6'84	6'60	17'39	4'61
135 - 139'5	6'45	6'84	7'11	6'52	1'54
140 - 144'5	4'52	2'14	9'14	6'52	6'15
145 - 149'5	5'16	5'55	5'08	8'69	-
150 - 154'5	6'45	3'42	11'17	2'17	7'69
155 - 159'5	10'32	0'85	4'06	-	1'54
160 - 164'5	5'81	1'71	4'57	8'69	-
165 - 169'5	4'52	2'14	2'54	2'17	1'54
170 - 174'5	2'58	1'28	2'54	-	-
175 - 179'5	3'87	1'71	2'03	-	-
180 - 184'5	2'58	0'85	1'52	2'17	3'08
185 - 189'5	1'29	1'28	0'51	-	3'08
190 - 194'5	1'29	0'85	1'01	2'17	-
195 - 199'5	0'64	-	1'01	2'17	-
200 - 204'5	1'29	0'43	1'01	-	1'54
205 - 209'5	0'64	-	2'03	-	-
210 - 214'5	1'29	-	1'52	2'17	1'54
215 - 219'5	0'64	-	0'51	-	-
220 - 224'5	-	-	0'51	-	1'54
225 - 229'5	0'64	0'43	1'52	-	1'54
230 - 234'5	-	-	-	-	-
235 - 239'5	0'64	-	0'51	-	-
240 - 244'5	-	-	0'51	-	-
245 - 249'5	-	0'43	-	-	-
250 - 254'5	-	-	0'51	-	-
255 - 259'5	-	-	-	-	-
260 - 264'5	-	-	-	-	-
265 - 269'5	-	-	-	-	-
270 - 274'5	-	-	0'51	-	-
275 - 279'5	-	-	-	-	-
280 - 284'5	-	-	-	-	-
285 - 289'5	-	-	-	-	-
290 - 294'5	-	-	0'51	-	-
	99'93	99'98	100'01	99'94	99'99
No. total	155	234	197	46	65
Peso medio	124'55	122'05	143'30	132'40	124'95
Desviación típica	33'85	31'60	41'10	33'50	39'65
Error típico medio	2'72	2'07	2'93	4'94	4'92

Cuadro IV

Relación talla-peso. Barbate 1961

Intervalos de clase cm	"Derecho"		"Revés"		
	N	Peso medio Kg	N	Peso medio Kg	% pérdida
140 - 144'5	1	74'0	1	60'0	18'9
145 - 149'5	2	76'5	4	54'2	29'1
150 - 154'5	5	74'8	6	61'7	17'5
155 - 159'5	7	82'1	5	68'6	16'4
160 - 164'5	3	86'7	6	70'8	18'3
165 - 169'5	1	100'0	2	74'5	25'5
170 - 174'5	3	107'3	5	89'0	17'0
175 - 179'5	5	115'4	6	95'3	17'4
180 - 184'5	12	119'0	13	101'0	15'1
185 - 189'5	11	127'6	31	106'4	16'6
190 - 194'5	24	134'8	37	114'0	15'4
195 - 199'5	26	149'2	22	124'2	16'7
200 - 204'5	21	161'0	29	128'9	19'9
205 - 209'5	12	168'6	23	139'6	17'2
210 - 214'5	8	176'1	15	152'5	13'4
215 - 219'5	5	186'4	12	163'0	12'5
220 - 224'5	3	195'0	8	174'0	10'8
225 - 229'5	4	211'7	4	184'0	13'1
230 - 234'5	1	228'0	2	198'0	13'1
235 - 239'5	1	236'0	1	225'0	4'7
240 - 244'5	-	-	-	-	-
245 - 249'5	-	-	1	247'0	-
	155		233		M = 16'4

Cuadro V

Longitudes, pesos y edades del atún de Barbate durante el período 1956-1959

Edades en años		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Long. zool. medias en cm.		55'3	79'o	116'2	13o'1	146'9	165'1	178'1	192'9	2o6'5	22o'3	232'o	244'o	255'o
Peso Kg.	"Derecho"	3'3	1o'4	35'5	44'5	61'1	9o'7	1o5'8	142'4	165'o	2o5'5	-	-	-
	"Revés"			34'o	44'3	61'7	76'2	94'6	111'2	15o'o	164'o	166'o	239'o	-

Cuadro VI

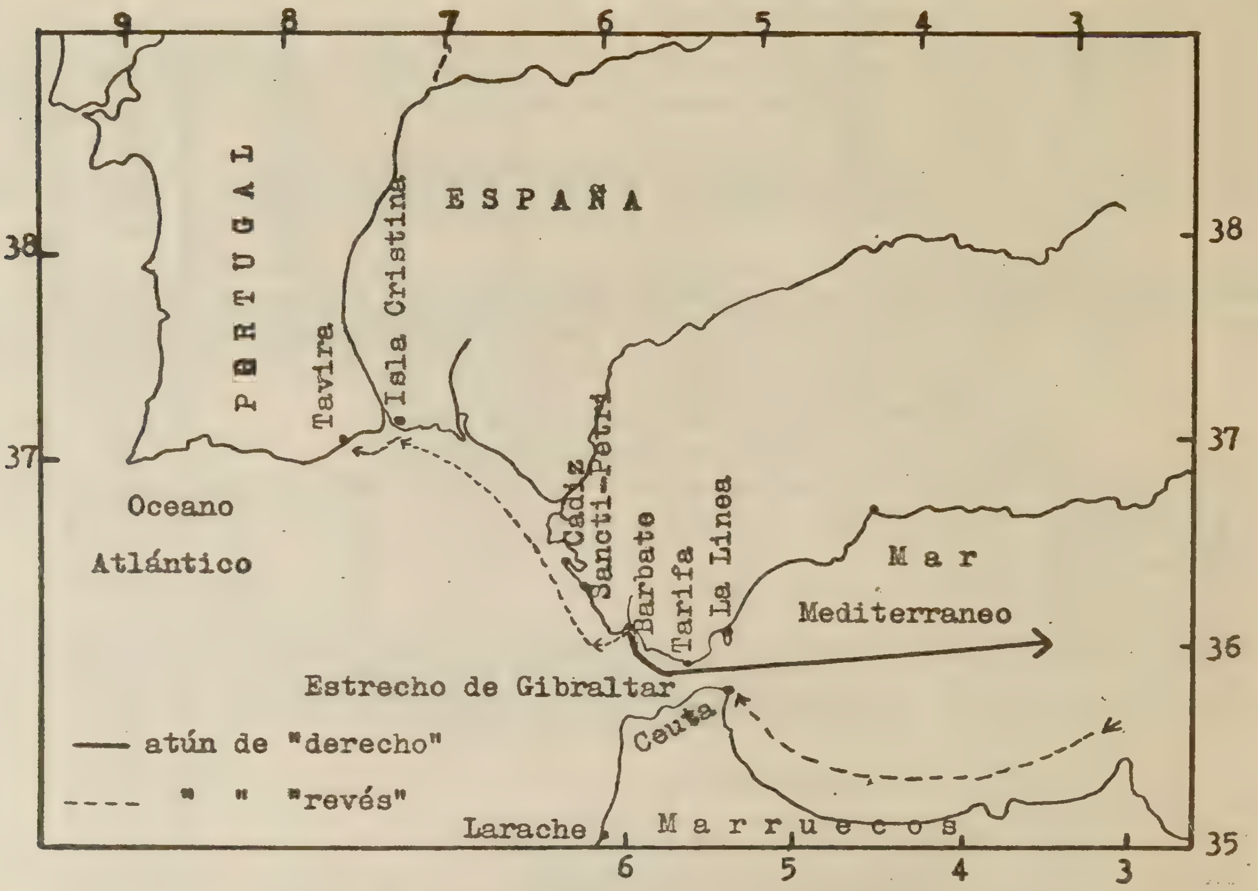
Porcentaje de edades de los atunes capturados por la almadraba de Barbate para el año 1961

Edad en años	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Porcentaje				o'68	4'31	6'36	1o'91	39'54	21'81	13'18	2'95	o'23
N				3	19	28	48	174	96	58	13	1

Cuadro VII

Tallas observadas y calculadas del *Thunnus thynnus* de Barbate

Edades	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Tallas observadas	55'3	79'o	116'2	13o'1	146'9	155'1	178'1	192'9	2o6'5	22o'3	232'o	244'o	255'o
Tallas calculadas	55'6	81'4	1o5'1	126'7	146'4	164'4	18o'9	195'9	2o9'7	222'3	233'8	244'3	253'2


PORTUGAL
ESPAÑA
Tavira
Isla Cristina
Cádiz
Sancti-Petri
Barbate
Tarifa
La Linea
Oceano Atlántico
Mar Mediterraneo
Estrecho de Gibraltar
Ceuta
Larache
Marruecos
atún de "derecho"
" " "revés"
9
8
7
6
5
4
3
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36
35

Fig. 1. Localidades del Golfo de Cádiz, en que se calan almadrabas para la captura del atún, y dirección más probable seguida según las recapturas.

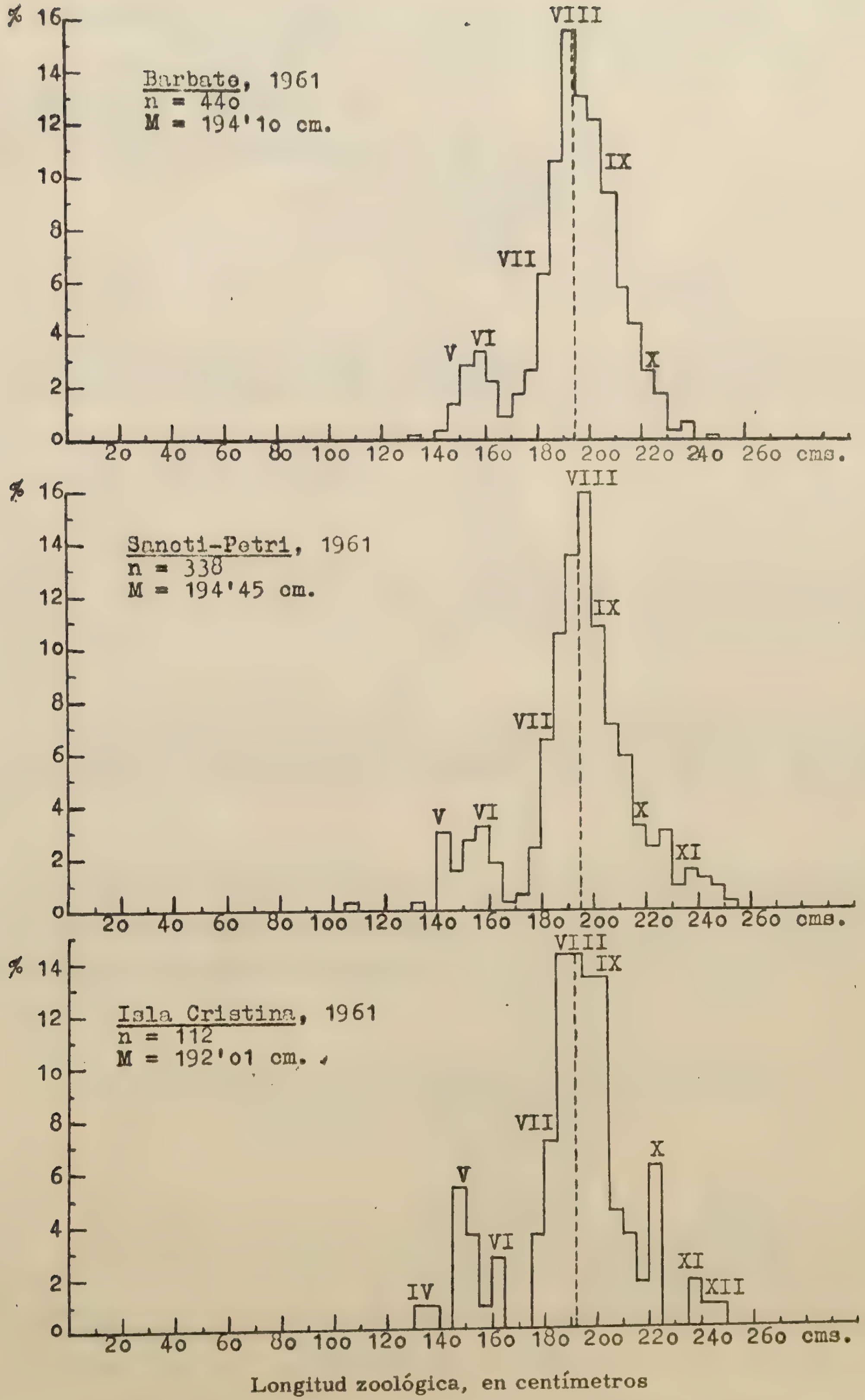

Fig. 2. Frecuencias de tallas del atún, Thunnus thynnus

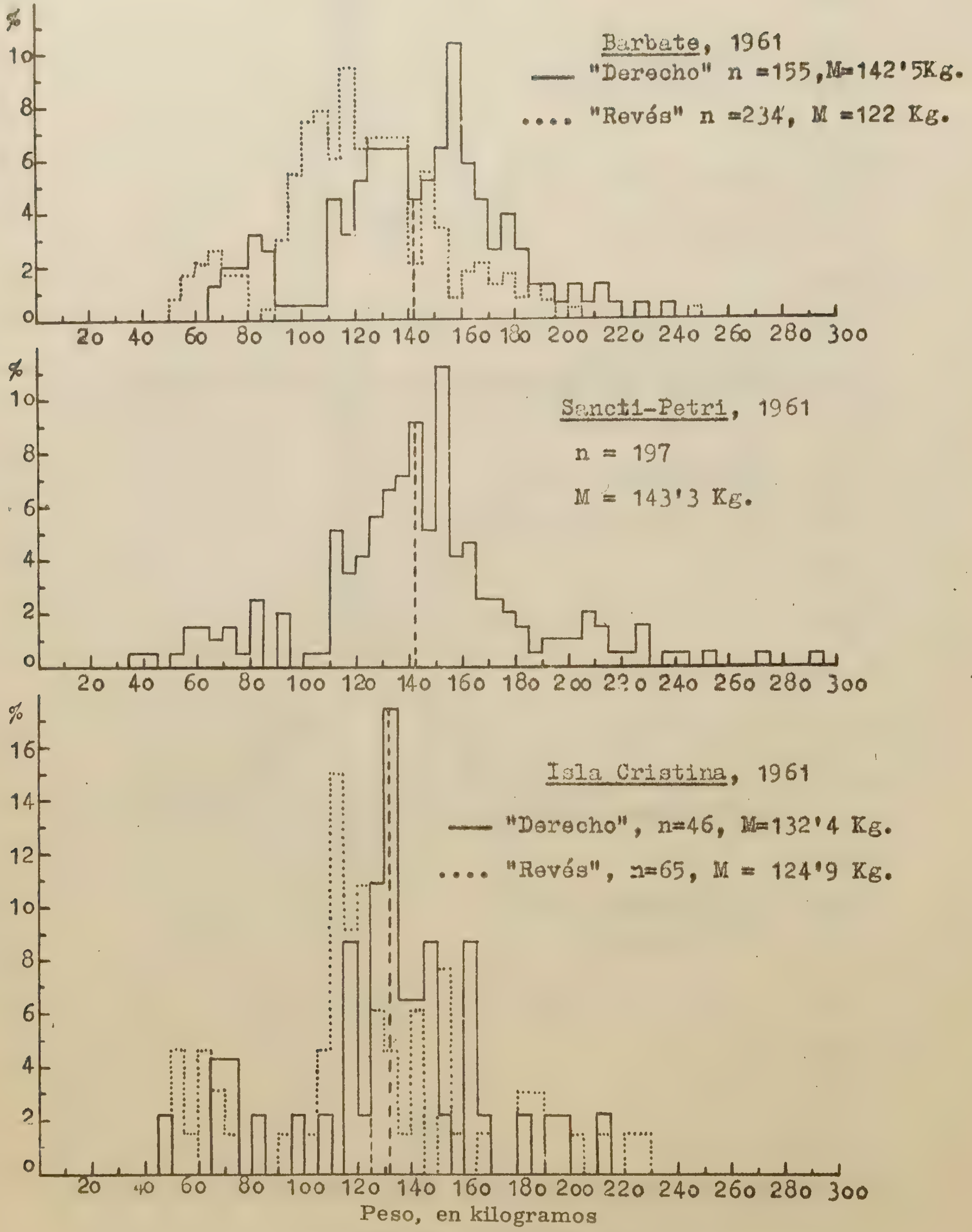

Fig. 3. Frecuencias de pesos del atún, Thunnus thynnus

Experience Paper No. 47 [1]

DISTRIBUTION AND RELATIVE ABUNDANCE OF TUNAS IN RELATION TO THEIR ENVIRONMENT

By

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University of Hawaii
Honolulu, Hawaii

and

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Food and Agriculture Organization of the United Nations
Rome, Italy

Abstract

A discussion of world tuna distribution and fishing areas in relation to temperature, depth, currents, transparency of water, food, submarine topography and meteorological factors. Maps of world distribution, fishing grounds and methods are included.

REPARTITION ET ABONDANCE RELATIVE DES THONS EN FONCTION DE LEUR MILIEU

Résumé

Commentaire sur la répartition du thon dans le monde et sur les zones de pêche en fonction de la température, de la profondeur, des courants, de la transparence de l'eau, de la nourriture, de la topographie sous-marine et des facteurs météorologiques. Cartes de la répartition mondiale du thon, des zones et des méthodes de pêche.

ABUNDANCIA RELATIVA Y DISTRIBUCION DE TUNIDOS CON RELACION A SU AMBIENTE

Extracto

Examina la distribución mundial y zonas de pesca de túnidos con respecto a la temperatura, profundidad, corriente, transparencia del agua, alimento, topografía submarina y factores meteorológicos. Da mapas de la distribución mundial, zonas y métodos de pesca.

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[1] This paper was originally submitted to the World Scientific Meeting on the Biology of Tunas and Related Species as Information Paper No. 2.

1 INTRODUCTION [1]

Each tuna species has particular environmental requirements for optimum growth and abundance. These requirements overlap to some extent, as would be expected for closely related species. Nevertheless, it would seem quite possible to characterize the optimum environment for each tuna species when more data and more specific data become available. Clemens (1961b) found that, despite some mixing of species, areas of heavy catch were quite different. For example, the majority of bluefin would avoid areas preferred by albacore, and vice versa.

To predict good fishing locations, we must describe and define the optimum environmental requirements for each species. One generally accepted clue is that the best fishing is done where the optimum environmental conditions occur in narrow bands.

Brock (1959) has published worldwide distribution maps and described, in general terms, relations between tuna behavior, oceanographic features and food occurrence and abundance. Many factors interact simultaneously to affect tuna behavior. So far, these relations cannot be treated mathematically. This paper attempts to describe known relations between tuna distribution and relative abundance and to describe widely-valid environmental factors not necessarily connected with local features.

The description is based on the maps (Figs. 1 to 9) of world distribution and fishing areas of the species. The information contained in these maps has been compiled from various contributions to the meeting. It was also provided by Dr. M.B. Schaefer, and Messrs. J.L. Squire, S. Springer, G.V. Howard and W.L. Klawe, of the United States, M.N. de Moraes of Brazil, F. Williams from Zanzibar, F. Talbot from South Africa, A.C. de Vildoso from Peru, J.P. Wise of FAO, S. Jones from India, to whom the authors wish to express their gratitude.

Information on fishing methods, from the same sources above, is given in Figs. 13a and 13b at the end of this paper.

The scientific names are those listed by Collette and Gibbs (1962).

2 TEMPERATURE PREFERENCE AS RELATED TO SURFACE WATER TEMPERATURE

Temperature is an important factor affecting tuna behavior and distribution, although not always the main factor. It is easily measured and a good indicator of changes in other environmental factors. The direct influence of temperature on distribution surely breaks down in the tropics, where temperature is relatively uniform throughout the year. But even here, small temperature differences can indicate current boundaries, areas of slow upwelling and other spots where tuna gather. Tropical tuna certainly respond directly to temperature changes at the northern and southern extremes of the distribution range. (Schaefer 1961). Therefore, landings are significantly greater near the boundaries during years of above-normal temperatures (Johnson 1961).

Fig. 10 shows the temperature ranges of normal distribution, fishery and optimum temperatures for catch. These ranges are based on a literature survey.

A variety of local and seasonal factors may cause some slight local differences in the optimum temperatures. For example Clemens (1961a) and Alverson (1961) concluded that albacore abundance is greatest along the North American coast at water temperatures from 15° to 20°C. Schaefer (1961) said yellowfin is found in commercial quantities off California at temperatures above 19°C, and skipjack above 16°C.

Some more temperate water species such as albacore and bluefin, seem to undertake seasonal migrations controlled by temperature, food or both. Highest concentrations of these species are usually where there is a high surface temperature gradient and where the optimum temperature zone is narrow. These species migrate polewards during summer, close to the zones of high horizontal gradients, and back toward the Equator during winter. Fig. 1 to 9 and Fig. 11 show some further general, and/or local, species distribution features in relation to surface temperature.

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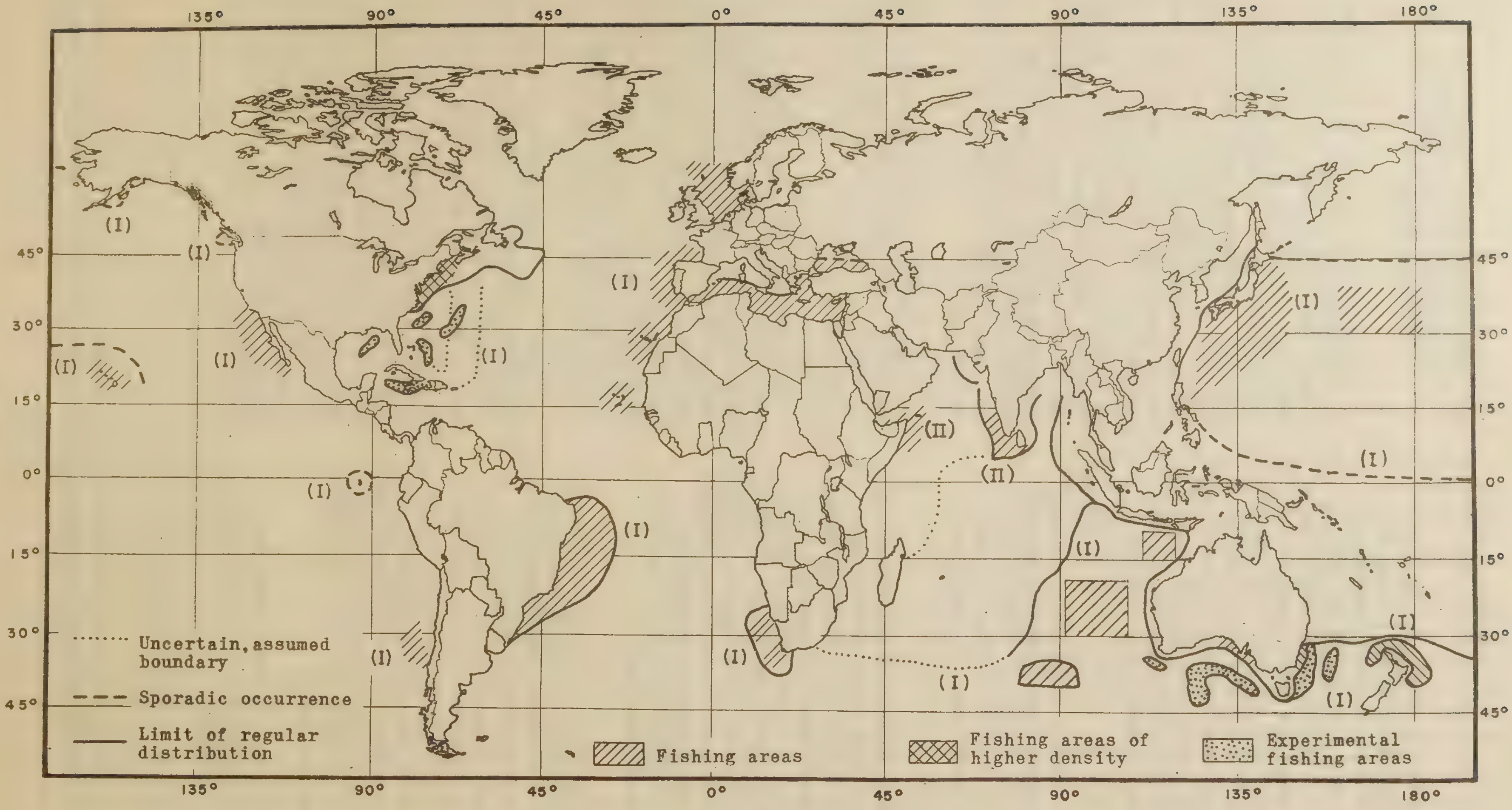
[1] This paper is a revision of a manuscript by Rosa and Laevastu (1961) distributed for information in connection with the informal Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961.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Uncertain, assumed boundary
Sporadic occurrence
Limit of regular distribution
Fishing areas
Fishing areas of higher density
Experimental fishing areas

Fig. 1 Distribution and fishing areas of bluefin tunas (I) Thunnus thynnus and (II) T. tonggol

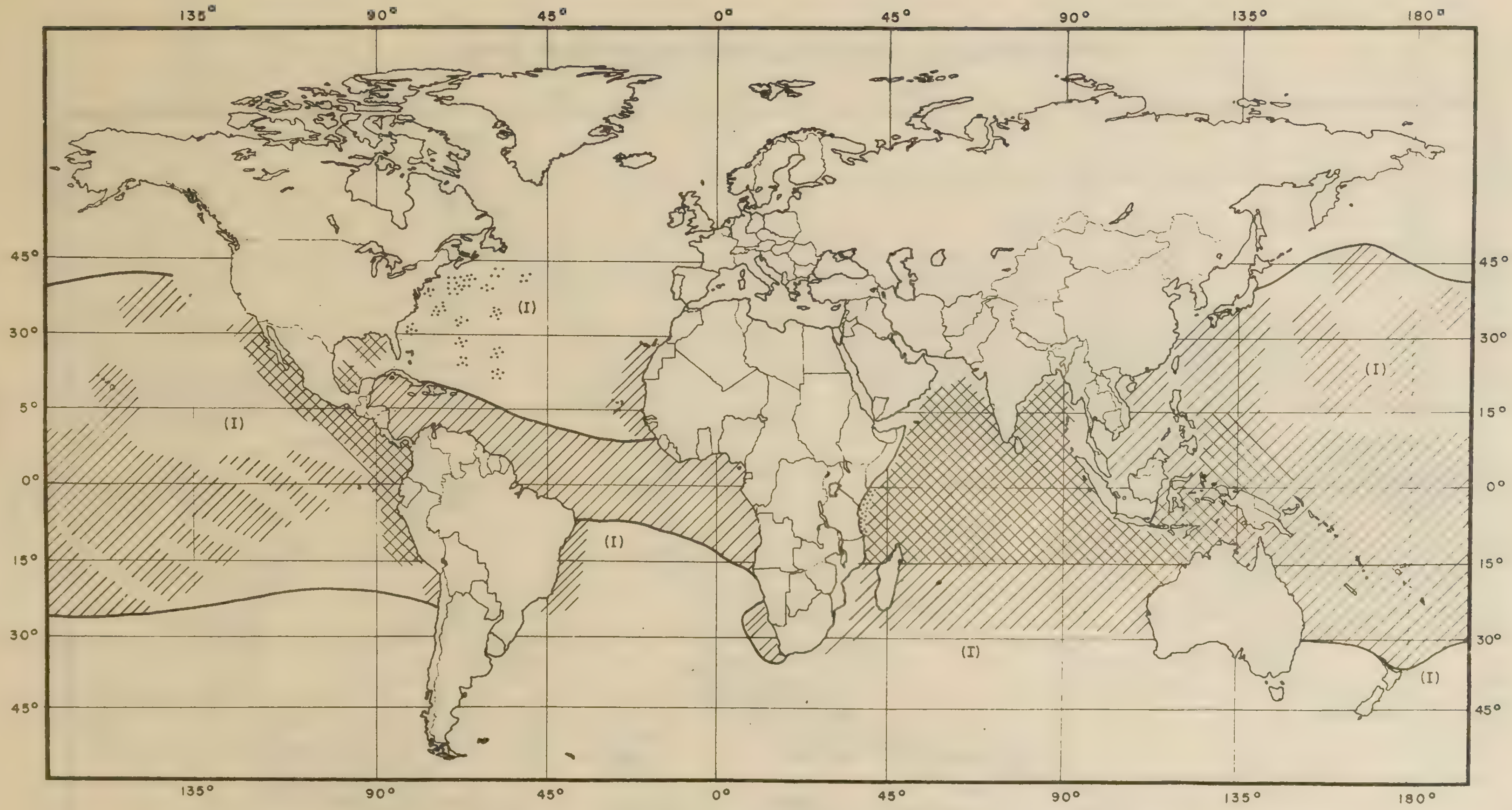
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Fig. 2 Distribution and fishing areas of yellowfin tuna (I) Thunnus albacares

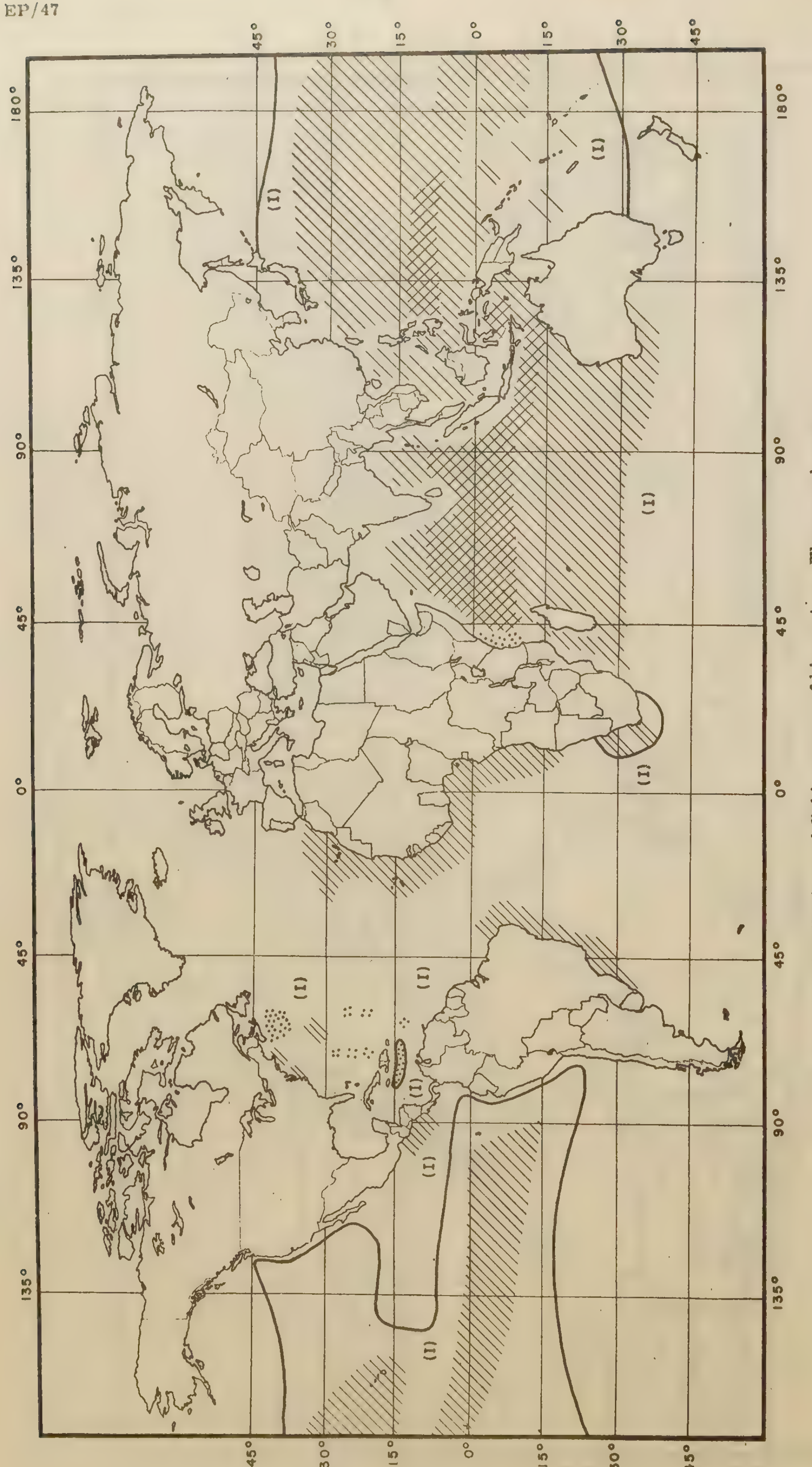
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Fig. 3 Distribution and fishing areas of bigeye tuna *Thunnus obesus*

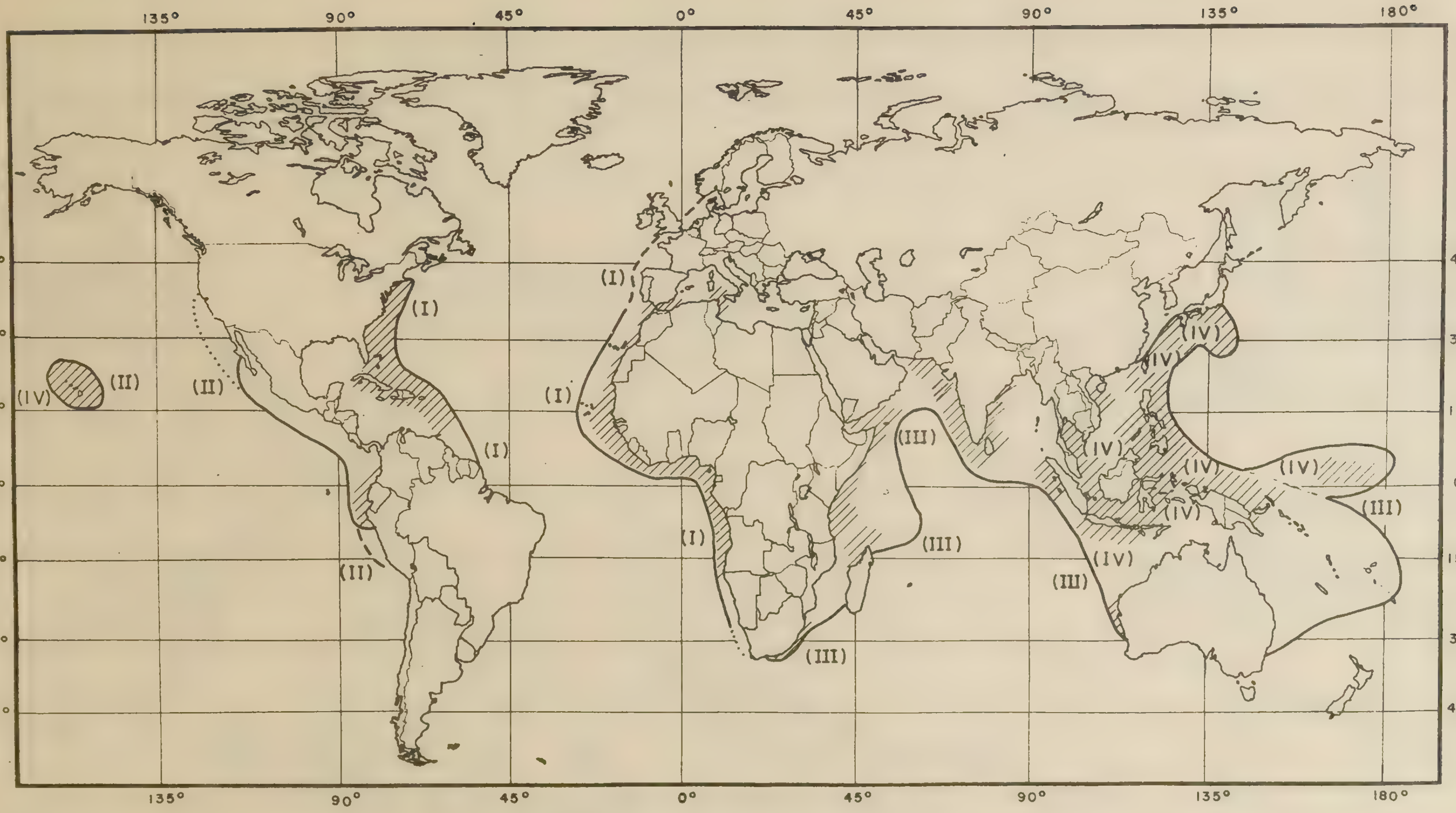
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Fig. 4 Distribution and fishing areas of little tunas (I) Euthynnus alletteratus
(II) E. lineatus (III) E. affinis (IV) E. yaito

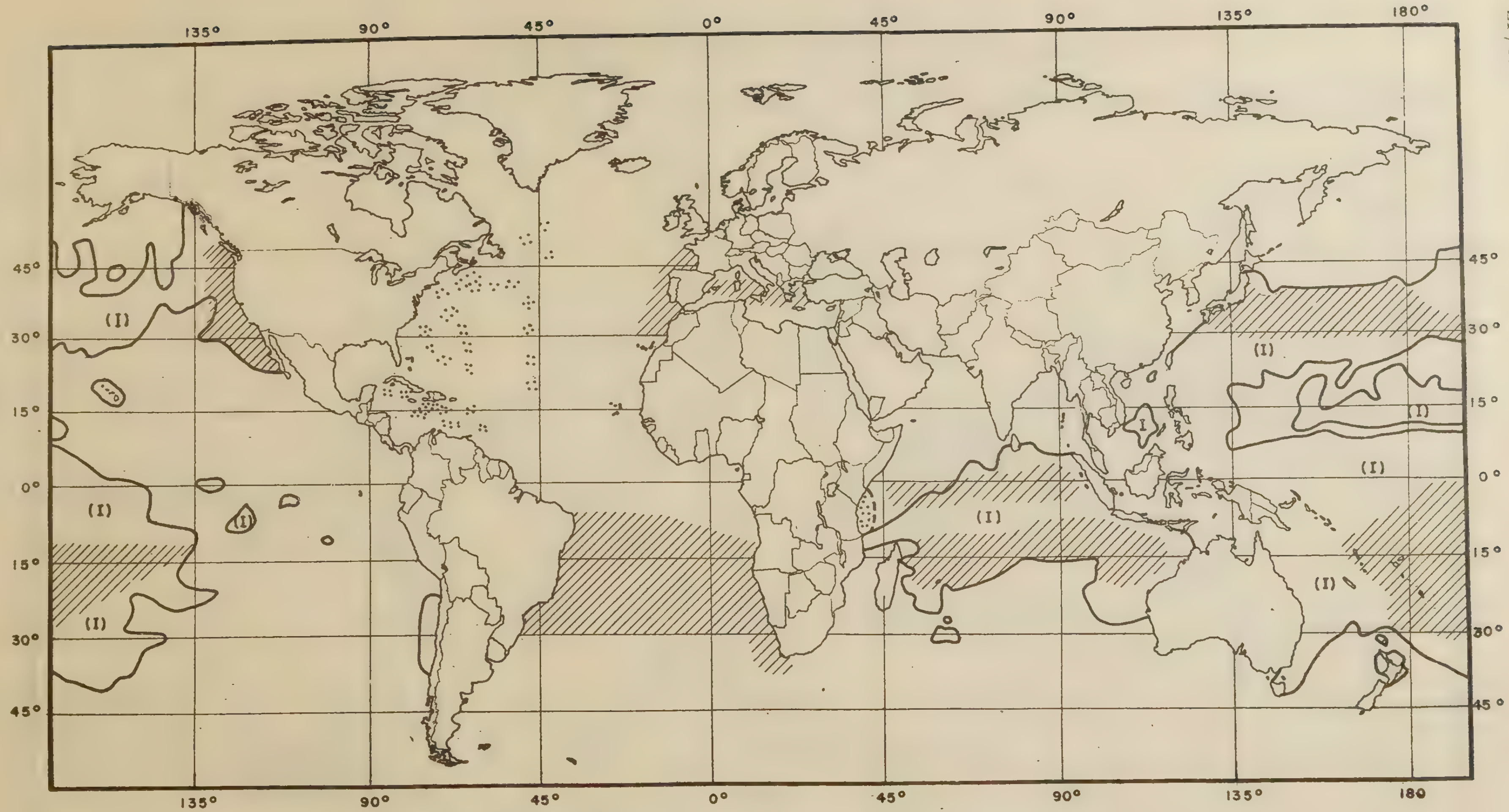
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Fig. 5 Distribution and fishing areas of albacore (I) Thunnus alalunga

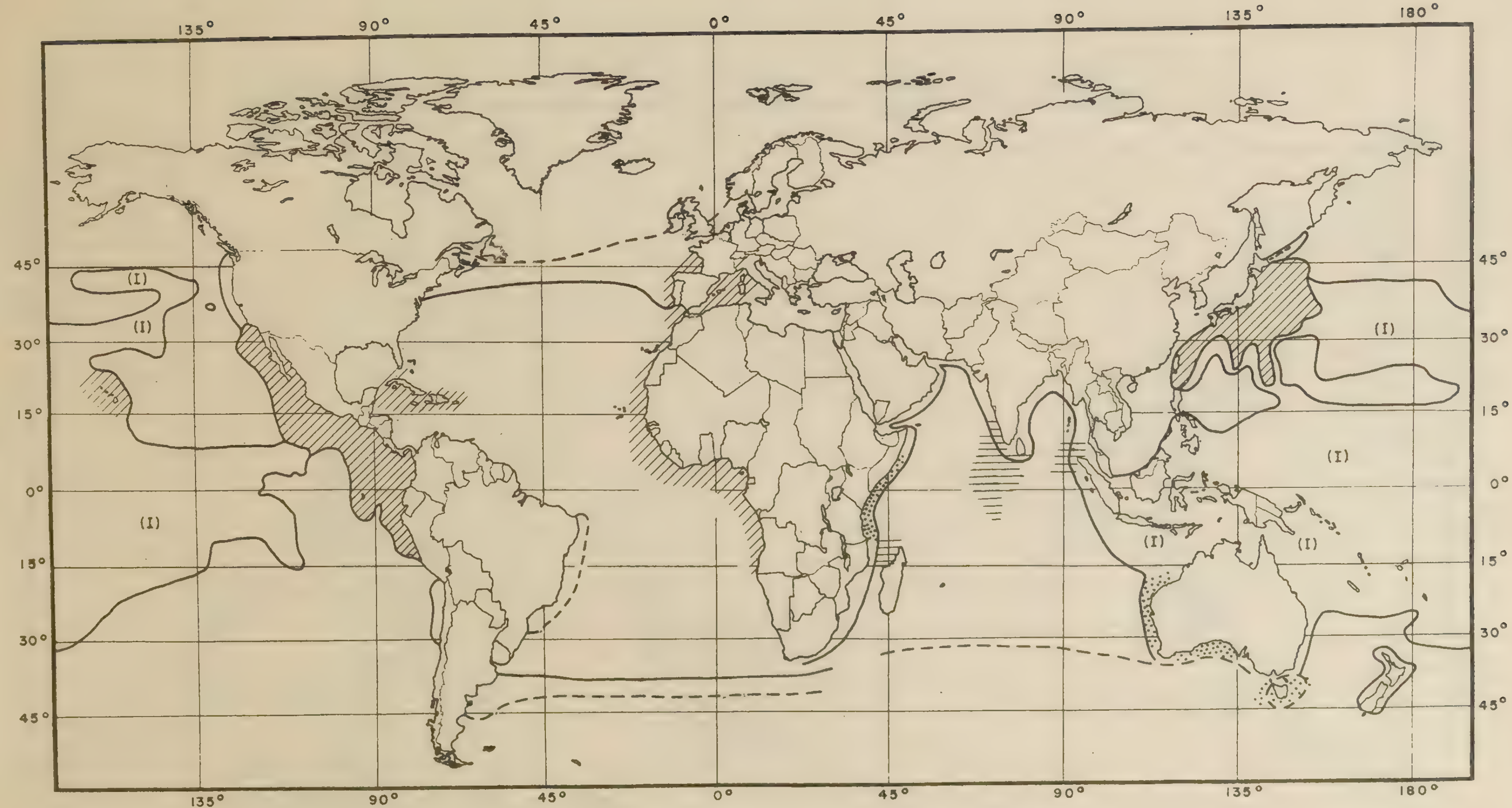
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Fig. 6 Distribution and fishing areas of skipjack (I) Euthynnus pelamis

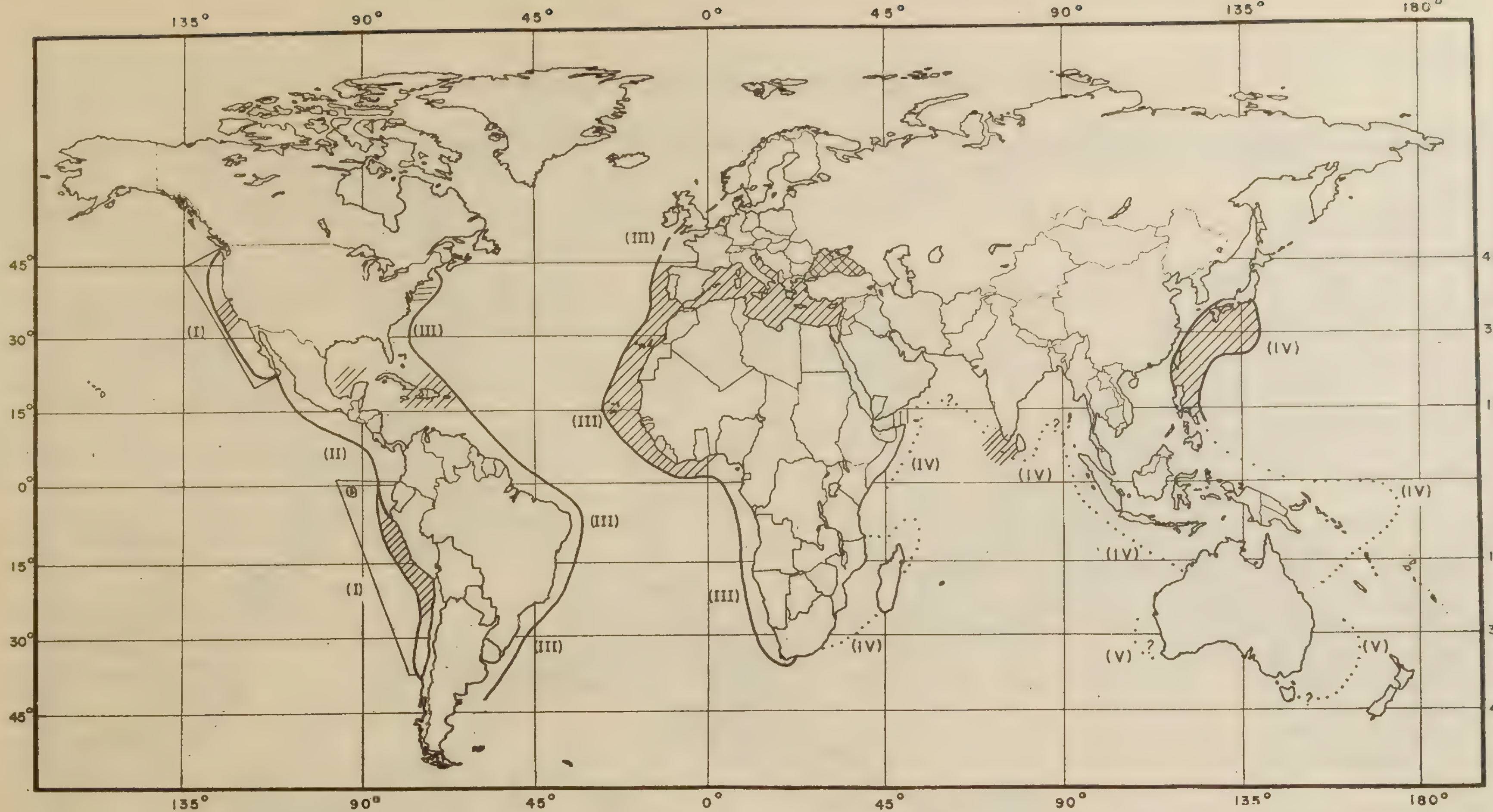
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Fig. 7 Distribution and fishing areas of bonitos (I) *Sarda lineolata* = *S. chilensis* (II) *S. velox* (III) *S. sarda* (IV) *S. orientalis* (V) *S. australis*

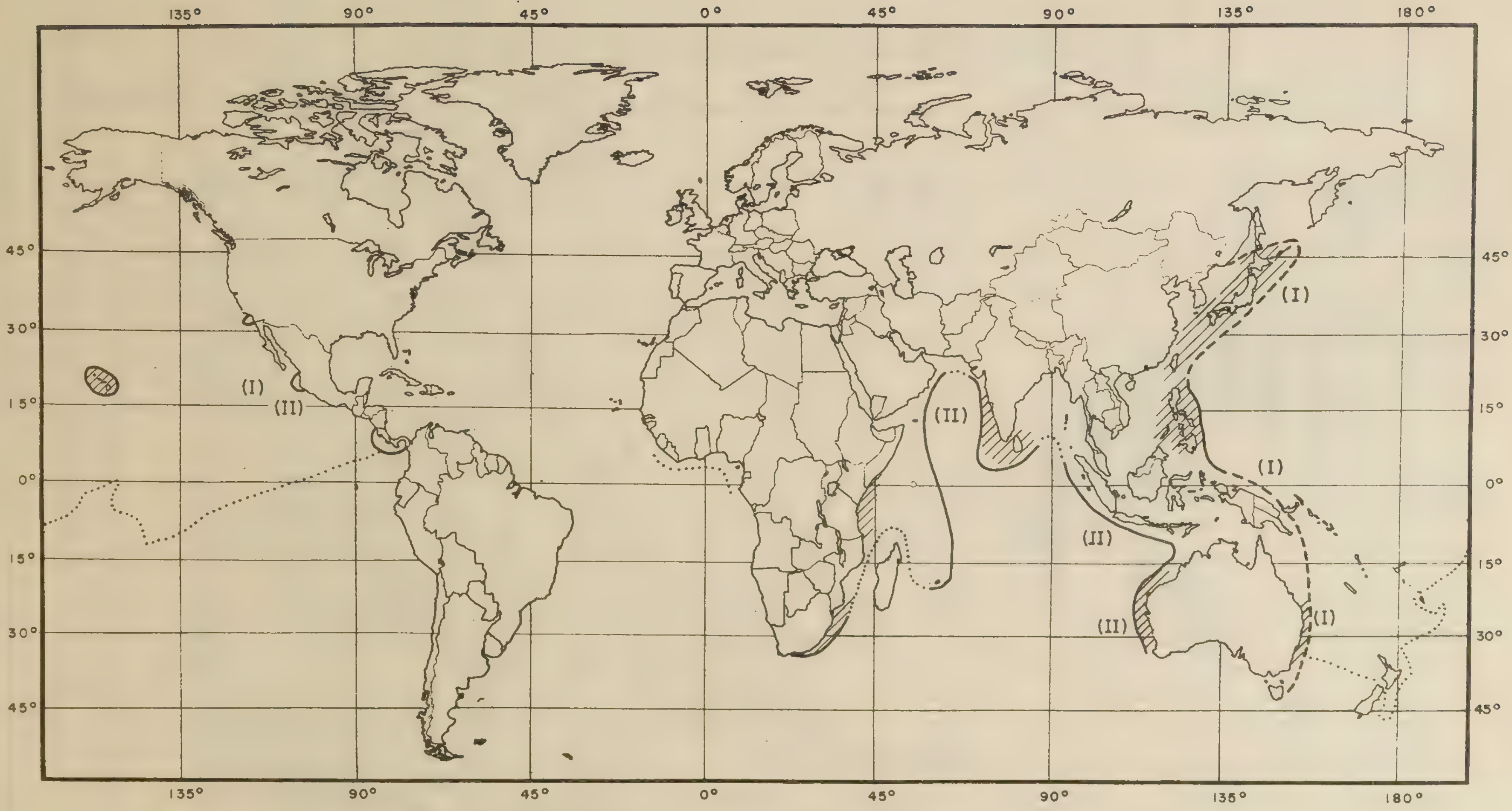
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Fig. 8 Distribution and fishing areas of frigate mackerel (I) *Auxis thazard*
(II) *A. rochei*

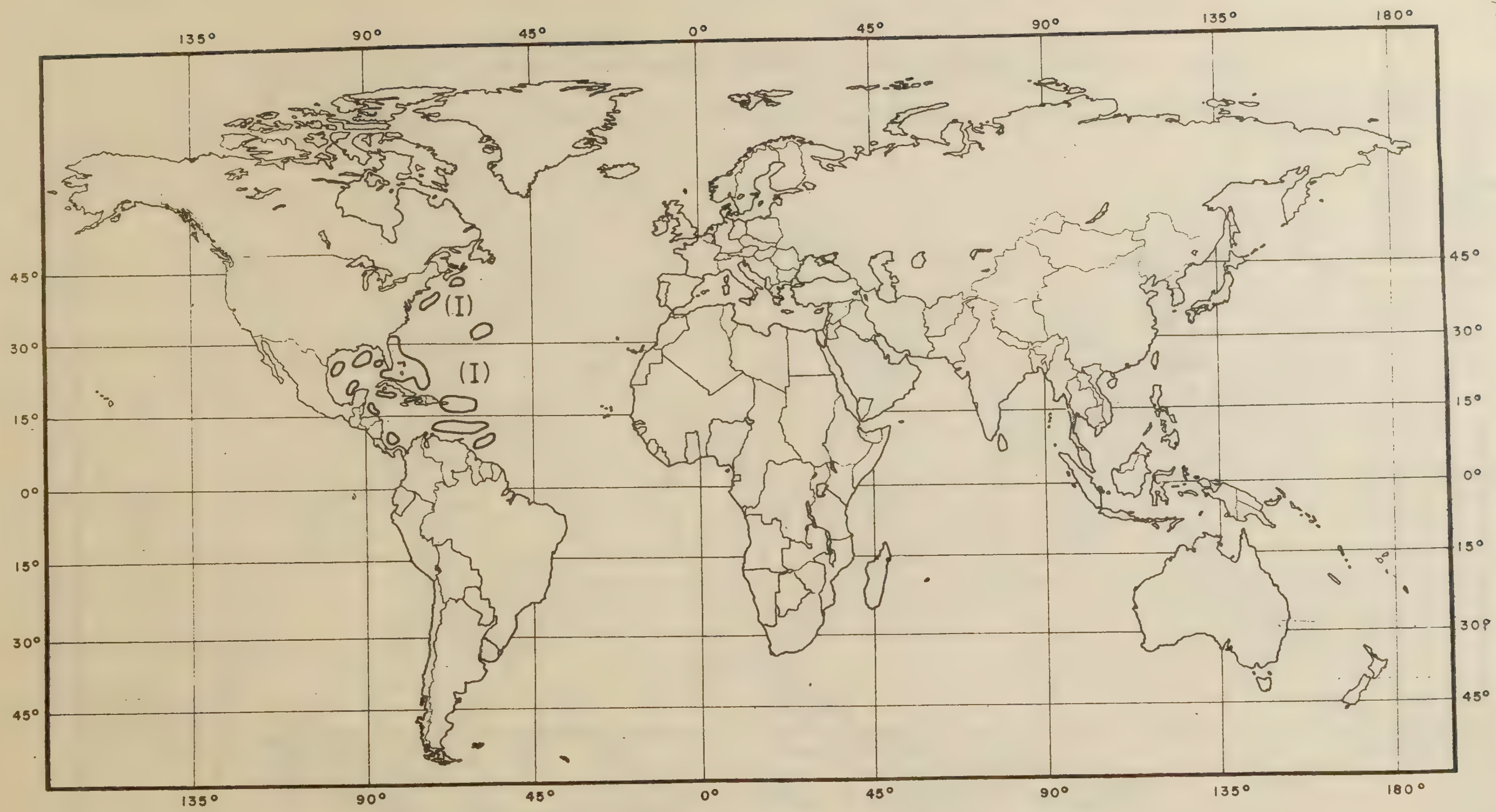
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Fig. 9 Distribution and fishing areas of blackfin tuna (I) Thunnus atlanticus

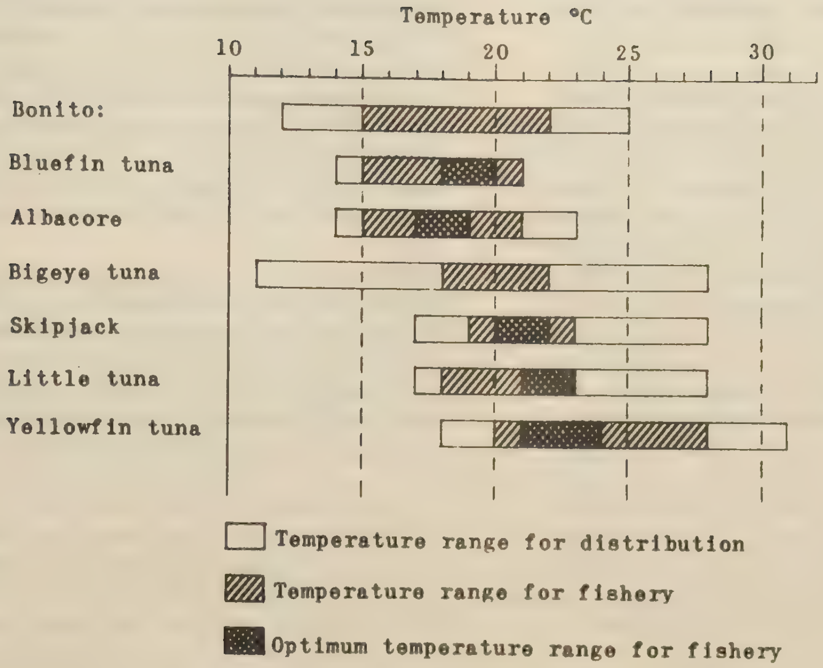
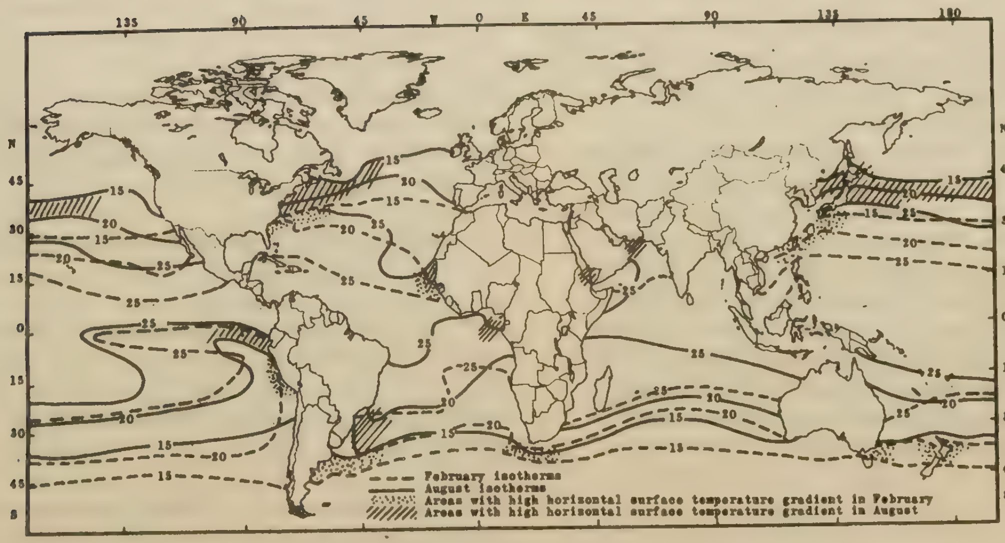


Fig. 10 Temperature spectra for tunas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February isotherms
August isotherms
Areas with high horizontal surface temperature gradient in February
Areas with high horizontal surface temperature gradient in August

Fig. 11 15°, 20° and 25°C surface isotherms during February and August and areas of high horizontal temperature gradient

3 DEPTH PREFERENCE, RELATIONS TO THE THERMOCLINE, DIURNAL MIGRATIONS

Pronounced temperature gradient, either horizontal or vertical or both, acts as a barrier and can cause aggregation. The literature contains relatively few data on absolute or comparative depth preferences of tuna. The vertical temperature structure is also important for both horizontal and vertical distribution, but this subject has not been sufficiently analyzed to allow definite conclusions. Thermocline ridges seem to be preferred places for aggregation. In these places however, the more abundant food seems to be the direct reason for aggregation.

It is generally stated that yellowfin occur mostly close to the surface. Clemens (1961b) concluded that bluefin tuna is found in greater quantities in areas with relatively shallow summer thermocline and a deeper one in the winter.

It is known that yellowfins, bigeyes and little tunas have daily vertical migrations. They are also attracted by artificial of medium strength, but repelled by strong light. They occur in deeper water during the day and close to the surface during the night. In general, it has been observed that actively-feeding tunas occur close to the surface.

4 REACTIONS TO CURRENTS AND RELATIONS TO WATER MASSES AND TO CURRENT BOUNDARIES

Japanese researchers (Uda 1961a) found that the optimum current for good tuna fishing is 0.5 to 1.0 knots. No reactions of tuna in respect of current have been reported. The schools of several tuna species usually remain in a given current system (and/or water mass) for a season and may migrate from one current system to another during the seasonal changes. The water mass relation of skipjack is most clearly demonstrated by Seckel and Austin (1961) by relating the occurrence of the skipjack to the movement of the California Current Extension through the Hawaiian Islands chain. They believe that in this relation both biological (food) and dynamical factors may be involved.

Within a current system, tuna tend to aggregate at boundaries of water masses (convergences and divergences). These usually are mixing zones of different water masses and are usually more abundant in pelagic food. The so-called "frontal zone concentration theory" originates from Japanese scientists and has been most tested by them (see Uda 1961a). The convergence zones are usually indicated by driftwood and the presence of small fish at the surface, and the divergences by discolored waters and luminescence at night. Fishermen in tropical areas use these signs as tuna indicators.

It is known from fishing practices that if a fishing ground is crossed by a current boundary, the change of abundance might be abrupt at this boundary and the best fishing might be where the convergence in frontal zone is maximum, as indicated by temperature discontinuities, tidal rips and other factors (Uda 1959; Schaefer 1961).

Small-scale distribution data reveals that boundaries of cold and warm eddies and cold and warm water intrusions, or pockets, are preferred places for aggregation. In detail, aggregations may vary with species.

For example, Clemens (1961b) found more bluefin in large eddies. Japanese workers found bluefin at the frontal zones in cold water pockets in cool cyclonic eddies and in cooler coastal waters, or areas of upwelled water, or both.

Albacore occur at frontal zones in warm water pockets formed near the colder edge of the zone and occasionally in cold cyclonic offshore eddies.

Skipjack is usually found in the frontal zone where warm and cold tongues meet nearer to the warm edges and in warm tongues as well as in anti-cyclonic eddies.

5 SEASONAL MIGRATIONS AS AFFECTED BY ENVIRONMENT

Bluefin and albacore make seasonal north-south migrations to and from the polar front. For this reason the North American albacore fishery is very seasonal (Clemens 1961a). The occurrence of bluefin tends to be still more seasonal and sporadic than that of albacore. Yellowfin, which occurs in offshore areas in the equatorial region, is known to make only slight seasonal migrations between about 8°N and 8°S of the Equator.

Recent tagging results offer some idea of migration rates. Clemens (1961a) estimated that albacore in offshore waters migrate about 15 miles per day.

6 RELATION TO TRANSPARENCY OF THE WATER

The tunas live mostly in clear oceanic waters. Optimum transparency for tunas is 25 to 35 m. At higher transparencies, food is scarce. At lower transparencies, tuna have difficulty finding prey, including bait.

Murphy (1959) found gill-nets more effective for albacore in turbid waters than in clear waters. Troll catch was even more effective in clearer waters. Murphy also discusses the possibility that water clarity may be an important ecological factor in the ocean, in that the efficiency of sight feeders will be reduced as turbidity increases.

7 RELATION TO THE ABUNDANCE OF FOOD

McGary et al (1961) concluded that the temperature-tuna occurrence relation may be indirect and indicative, but associated food relation cause tuna aggregations.

Schaefer (1961) concluded tuna is most abundant where its forage is best. This can be verified by comparing Figs. 1 to 9 with Fig. 12. This shows generally that the best tuna fishing areas coincide with more productive areas in the tropics and medium latitudes. A general relation between tuna abundance and abundance of macro-plankton and small nekton holds true in general. But this breaks down sometimes in small-scale distribution, for various reasons (e.g. smallness of plankton patches, vertical migrations of macro-plankton and similar factors). Areas with a higher standing crop of plankton (convergences, "outer downstream edges" of upwelling areas, eddy centers and areas of mixing around islands and seamounts) are usually areas where tuna aggregate.

8 RELATION TO COASTS AND TO SUBMARINE TOPOGRAPHY

Bonitos and little tunas are mostly caught relatively close to the coast. Skipjack also occur in coastal areas. Further offshore the (probably separate) populations seem to be associated with certain island groups. Albacore, bigeye, and yellowfin mainly occur in the offshore areas.

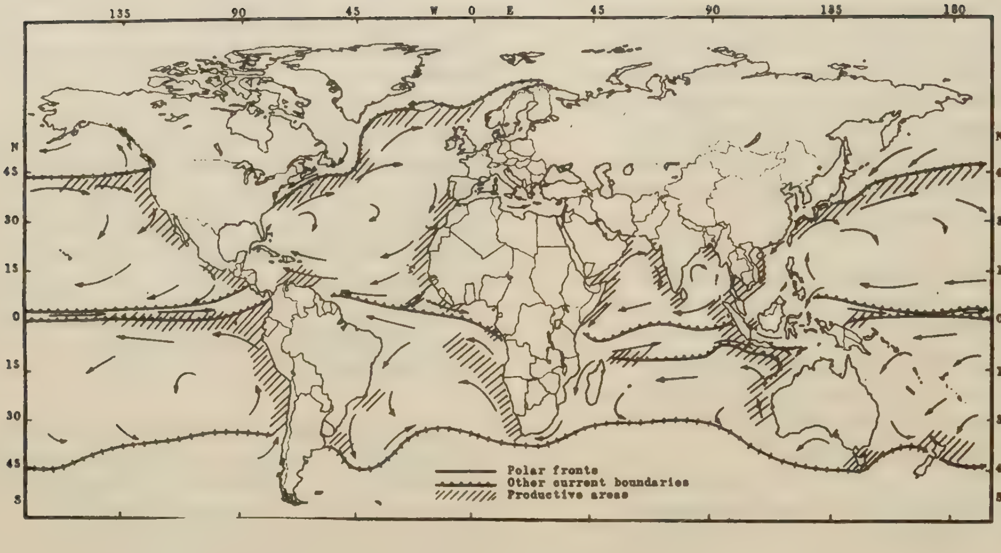
Shapiro (1950) stated that Japanese tuna fishermen use the configuration of ocean bottom, reefs, banks and islands for location of tuna concentrations, besides using the optimum water temperature and current boundaries. Clemens (1961b) also concluded that more bluefin is found where there are several islands and underwater banks and a long, narrow, shallow area along the continental land mass. It has also been observed that storms sometimes cause tuna to aggregate to leeward of the islands.

Topographical features affect the hydrography and the production or concentration of plankton (e.g. mixing by internal waves on slopes, eddies and mixing around islands and seamounts), thus affecting tuna behavior through food relation.

9. RELATION TO METEOROLOGICAL FACTORS

The changes of the environmental factors in the sea are directly caused by meteorological factors. Therefore a correlation between meteorological factors and tuna behavior can be found. It has been indicated that where stronger southern components of wind prevail, the yellowfin is found north of the Equator and where northeast winds prevail, the concentrations are found south of the Equator. Uda (1961b) describes the reciprocal relationships in the albacore and skipjack catches between the eastern and western Pacific. He relates this to the reciprocal variations in surface water temperature, which in turn is related to the variations of meteorological circulation over the North Pacific.

Several other relations between environment and tuna behavior and occurrence (described here earlier) can be related to meteorological factors upon proper analysis of interactions between the sea and the atmosphere in given localities. A proper basis for various forecasts for fisheries could thus be obtained.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Polar fronts
Other current boundaries
Productive areas

Fig. 12 Equatorial current systems and their boundaries (during northern winter) and productive areas in the oceans between the polar fronts.

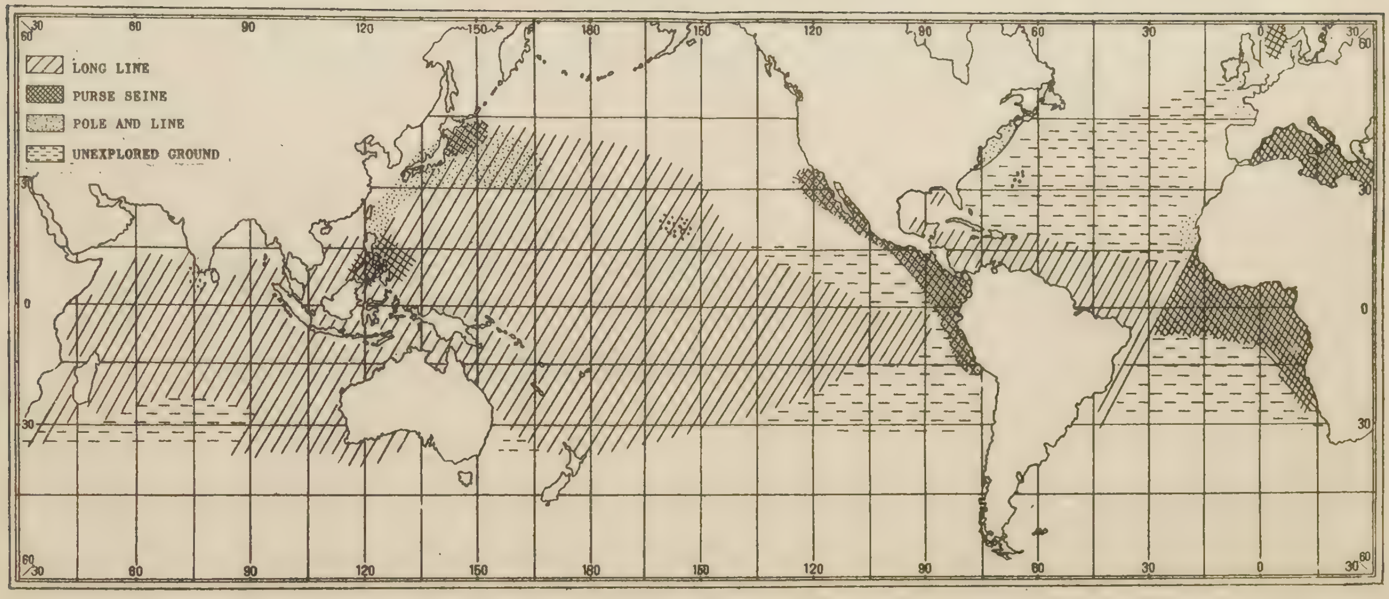
LONG LINE
PURSE SEINE
POLE AND LINE
UNEXPLORED GROUND
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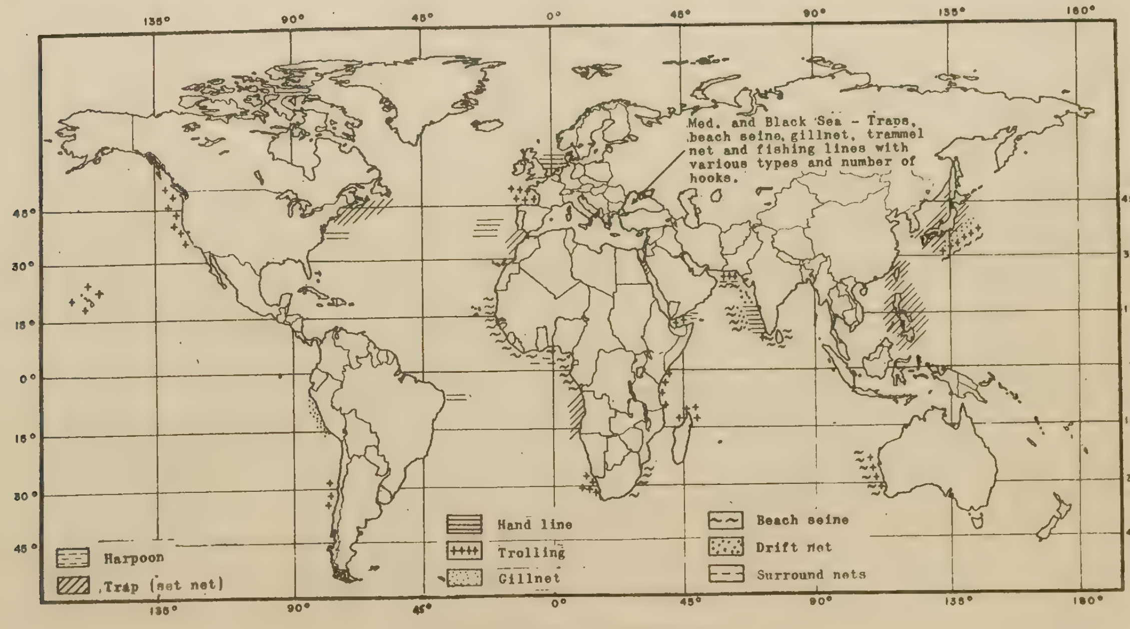
Fig. 13a Longline, purse seine, pole-and-line and unexplored tuna fishing grounds
(Adapted from H. Nakamura, Japan *in litt*, 1962)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Med. and Black Sea - Traps, beach seine, gillnet, trammel net and fishing lines with various types and number of hooks.
Harpoon
Trap (set net)
Hand line
Trolling
Gillnet
Beach seine
Drift net
Surround nets

Fig. 13b Miscellaneous tuna fishing methods

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